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THE INFLUENCE OF GAME DESIGN ON THE COLLABORATIVE PROBLEM SOLVING PROCESS: A CROSS-CASE STUDY OF MULTI-PLAYER COLLABORATIVE GAMEPLAY ANALYSIS

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Abstract

This cross-case study examines the relationships between game design attributes and collaborative problem solving process in the context of multi-player video games. The following game design attributes: sensory stimuli elements, level of challenge, and presentation of game goals and rules were examined to determine their influence on game player's collaboration and joint problem solving processes. Six participants were placed into four collaborative teams and asked to play at least one video game. Three multi-player video games were utilized: Portal 2, *Indiana Jones 2: The Adventure Continues*, and *Borderlands*. Seven cases were identified based on a combination of teams and video games. Data were collected via observations of teams' gameplay and discourse as well as through questionnaires filled by the participants. The data from these cases were analyzed at three levels: Within game/within case, within game/across cases, and across games.

The results of this study confirm the game design attributes' potential influence on collaborative problem solving. The findings of this study indicated that the sensory stimuli elements with guidance functionality were more effective in promoting collaboration. In addition, subtle sensory stimuli elements used for guidance purposes were more effective at enhancing the collaborative problem solving activity compared to the prominent sensory stimuli elements. It was also found that when participants felt more challenged due to a complex task they were more willing to work together to solve the problems. However, the increased challenge due to a difficult gameplay mechanics did not promote collaboration especially for the inexperienced teams. The influence of presentation of goals and rules on collaborative problem solving was not robust. This

study identified that ambiguous goals and rules promoted more conversation only for groups with healthy team dynamics therefore supported collaborative problem solving.

Findings from this study provide empirical evidence on which mechanisms of games promote collaborative learning and provide insight into how game design can support or inhibit collaborative learning.

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Chapter 1 - Introduction

Emerging technologies have long supported the broad umbrella of collaborative learning approaches (Stahl, Koschmann, & Suthers, 2006) including educational practices that engage learners to demonstrate shared intellectual effort (Smith & MacGregor, 1992). Among emerging technologies, multi-player video games provide users with various means to work together to accomplish a common game goal by completing a series of problem-oriented tasks. This dissertation study explores the design of multi-player video games and how specific game design attributes influence collaborative problem solving process. In order to understand the ways games influence collaborative learning, this study examines how the design of the games affects collaborative problem solving processes.

Problem solving has been the focus of the learning sciences and psychology fields since the early 1970s (Ormrod, 1999). The majority of the problem solving research conducted in the 1970s and 1980s was cognitivist and focused on understanding the individual's mind using positivistic methods. In the 1990s, a paradigm shift from the objectivist tradition changed the focus of research in this area to more towards constructivist approaches situating learning in authentic, interactive, and learner-centered experiences (Duffy & Jonnasen, 1992; Land & Hannafin, 2000). This period fostered a commonly referenced student-centered strategy: Problem-based learning (PBL) (Land & Hannafin, 2000; Savery & Duffy, 1996). PBL is an instructional approach in which solving a problem serves as the basis for the learning process (Graaff & Kolmos, 2003). Aside from the move towards student-centered learning environments, learning scientists also started to emphasize the social nature of cognition and shared meaning making

(Resnick, 1987; Roschelle & Teasley, 1995), as well as the role of social interactions in constructing knowledge (Barab & Duffy, 2000). As meaning making through social activities has gained prominence as a powerful alternative to information processing theories (Wilson & Myers, 2000), the popularity of utilizing collaborative learning activities in educational settings has increased.

Interactive digital systems such as computer-based programs (Roschelle & Teasley, 1995), videos (Barron, 2000a, 2003), and mobile platforms (Hoff, Wehling & Rothkugel, 2008; Klima, Cmolik & Slavik, 2006; Tai & Yang, 2008) are frequently utilized to support collaborative learning activities. Digital games have also emerged as prevalent platforms for collaborative problem solving (Leemkuil et al., 2003; Light et al., 1994; Manninen & Korva, 2005; Sancho et al., 2009). This emergence of digital games raised an essential instructional design related question: How should games be designed to increase the possibility of fostering collaborative problem solving? This research explores this question by examining a set of game attributes that are a part of the design process of the games. By studying how game design attributes influence collaborative problem solving; this study furthers understanding of the mechanisms through which games influence the process of collaborative problem solving. By explaining this mechanism of influence, this study contributes to the body of knowledge on the effective design of educational games to support collaborative problem solving activities.

Problem Statement

This study explores the intersection of digital games and collaborative problem solving. Existing literature reveals an increased interest in both of these phenomena independently during the last a few decades; however, there is lack of empirical research on the confluence of digital games and collaborative problem solving.

The field of educational game research has recently focused on the effectiveness of gameplay and the place of digital games in learning environments (Van Eck, 2006). Studies exist that explore the positive effects of gameplay on various types of academic learning including algebra, biology, computer programming (Barlett, Anderson & Swing, 2009); however, it has been suggested that researchers examine why and how games are effective learning tools (Van Eck, 2006) through understanding the relationship between game attributes and learning (Wilson et al., 2009). Of all the game attributes the game design literature identify, Garris et al. (2002) distinguish six key game attributes necessary for learning: fantasy, rules/goals, sensory stimuli, challenge, mystery, and control. This study examines the influence of three of these game attributes: challenge, rules/goals, and sensory stimuli that are relevant and essential to the problem solving process.

Similarly, collaborative problem solving has been researched in a variety of contexts including physics (O'Malley & Scanlon, 1990; Roschelle, 1992; Roschelle & Teasley, 1995), scientific literacy (Palincsar et al., 1993), secondary mathematics learning (Sarmiento & Stahl, 2008; Barron, 2003), and language teaching (Warschauer, 1997). Researchers have explored the use of a variety of tools and technologies such as computer programs, online platforms, simulations, and games (Barron, 2003; McGregor & Chi, 2002; Roschelle & Teasley, 1995; Sancho et al., 2009). Although digital environments have been used as media for collaborative problem solving activities, there is still a need for empirical studies that will extend our knowledge of how digital environments foster or inhibit collaborative learning. To fill this gap partially, this study examines the relationship between game attributes and the process of collaborative problem solving in digital games and explores how the design of digital games environments fosters or inhibits the collaborative problem solving process.

The intersection of collaborative problem solving and educational game fields has been evident in studies that research Massively Multi-player Online Role Playing Games (MMORPGs) or Massively Multi-player Online Games (MMOGs) as the collaboration environment (Galarneau, 2005; Voulgari & Komis, 2011). Numerous studies focus on MMORPGs and MMOGs to examine the online interactions, social roles and structure developed in the games, and their advantages as collaborative environments. Despite the existing research, there remains much to explore when it comes to the collaboration that takes place during a side-by-side digital game-play experience. This qualitative cross-case study explores the design of side-by-side multi-player games by exploring the relationship between game attributes (challenge, rules/goals, and sensory stimuli) and collaborative problem solving processes by studying face-to-face interactions and discourse between players during collaborative game play activity.

Conceptual Framework

Conceptual framework of this study was constructed based on a combination of concepts and theories residing in collaborative problem solving, problem-based learning, and game design literatures. These concepts and theories are discussed in the following sections.

Defining the nature and type of problem tasks encountered in digital games.

Collaborative problem solving in the context of multi-player games can be defined as the process of finding a mutually agreed solution to the problem encountered. All games present some set of problems to the player(s) and the nature of problems encountered in the games vary based on the game genre. Because it is not possible to include every game genre in this study, collaborative problem solving in the context of puzzle, adventure and action role playing games (RPG) is the focus of this research. Game play in these genres is characterized by exploration and solving puzzles while overcoming physical challenges that require hand-eye coordination and reaction-time. These chosen genres also include a variety of problem types and collaborative environments.

In a generic sense, problem solving can be explained as the process of exchanging aporias with epiphanies (Jorgensen, 2005). Based on Aarseth's (1999) work, Jorgensen (2005) defines aporia as a clearly defined problem that a player faces in a game and epiphany as a sudden and often unexpected solution to aporia. In action/adventure games problem solving can be identified as the player figuring out what to do to progress toward the goals established by the game. Although there may not be clearly defined aporias along the way, players should take strategic actions to be able to complete the tasks given to them (Jorgensen, 2005). In most cases, players have to collect resources, develop their character to be stronger, and engage in battles.

If we put some of these specific game aporias into a more familiar context we can better analyze the nature of the problems presented by the games and establish the problems' association to learning. In problem-based learning literature, Jonnasen (2000) constructed taxonomy of the problems learners face in educational settings. Jonnasen's taxonomy establishes 11 types of problems: logical, algorithm, story, rule-use, decision-making, troubleshooting, diagnosis-solution, strategic performance, case analysis, design, and dilemma problems.

Logical problems are solved through reasoning in which the learner has to find the specific method of reasoning that will result with the most efficient solution (Jonnasen, 2000). During action/adventure game play, players sometimes encounter with logical problems that typically involve overcoming a puzzle. This type of problem in games requires players to utilize game rules, concepts, and principles into their logical and analytical thinking. An example of a logical problem in a game might have a player trying to figure out the missing piece of a security code to defuse a bomb with given clues. Rule using problems do not require learners to use a specific method or procedure to obtain the solution but still provide a clear end goal (Jonnasen, 2000). Most board games, such as chess, checkers, and some digital games consist of rule using problems (Jonnasen, 2000). Players are required to solve these problems through applying the rules provided to them to generate strategies in order to successfully complete the game. Modern digital game environments enforce their rules on the players both explicitly and implicitly - all the tasks that a game provides to its players are bounded by rules. In some cases overall game play can be considered as one big overarching rule using problem-solving activities.

Decision-making problems are also commonly encountered in action/adventure games. Jonnasen defines decision making problems as selecting a single option from a set of choices based on criteria (Jonnasen, 2000). In action/adventure games, players constantly select which missions to complete, which gun to use, or what type of ammunition to buy with the limited money they have. The results of what mission the player chooses influence the whole game. The gun a player chooses affects the player's performance in the game; the type of ammunition a player selects can make a big difference in a battle. Players have to make decisions that will either help them successfully complete their missions or contribute to their failure. Solving a strategic performance problem requires a combination of decision making and improvisation while maintaining situational awareness (Jonnasen, 2002). This complex problem solving necessitates players to employ a number of tactics to accomplish a strategy (Jonnasen, 2000). An example of a strategic performance problem in an action/adventure game could be identifying tactics in a combat situation to lead the player's team to victory.

Jonnasen (2000) defines dilemma problems as ill-structured problems that requires compromises to be made in every solution. They are amongst the rare problems a player faces in an action/adventure game. In some games players may be asked to make a social or ethical decision where the outcome will not affect the completion of the objective. For example, in *Bioshock 2*, players are given a choice to rescue or a harvest (by eliminating her) a little girl to gain more power in the game. Although this situation sounds like a strategy problem that player should tackle to complete the game successfully, it can also be considered as an ethical dilemma that a player faces. Players can kill the little girl and gain more points or save her and gain relatively low points. It is important to note that dilemma problems are generally considered to contribute to the common good of society in the context of real life, and solutions for dilemmas in real life can have important consequences and implications. On the other hand, dilemmas players face in game environments merely have the same magnitude of effect compared to real life dilemmas, but they still present a similar problem structure.

Collaborative problem solving and joint problem space.

Collaborative learning has been defined as “a situation in which two or more people learn or attempt to learn something together” (Dillenbourg, 1999). Collaborative learning can be broad and loosely characterized based on three elements: scale of collaboration, meaning of learning, and ways of collaboration (Dillenbourg, 1999). The broad concept of learning in collaborative settings includes the activity of joint problem solving that result with learning or enhancement of problem solving performance (Dillenburg, 1999). Collaborative problem solving, aka the activity of joint problem solving, is commonly associated with constructing a joint problem space, which is defined as a collective knowledge structure built through negotiating and sharing meaning (Roschelle & Teasley, 1995).

The notion of problem space comes from the general problem solving theory generated by Newel and Simon (1972) based on the information processing theories. Explained by Simon (1978), problem-solving activity is defined as applying “operators” to the “states.” States are data structures that define possible stages of progress in the problem solving. Operators change a state through interactions. A problem space is the collection of these states and operators that are available to the player to achieve the goal. Problem solving is the process of moving from the initial state in the problem space towards the desired state by using operators to transform one state to another. A similar notion that goes beyond being a collection of problem space concepts that is founded on information processing theories (Sarmiento & Stahl, 2008) can be found in the collaborative problem solving literature.

The joint problem space (Roschelle & Teasley, 1995) is a shared knowledge structure that is built through integrating goals, descriptions of the current problem state, awareness of possible actions, and associations between them. Collaborative problem solving occurs through negotiating, sharing and constructing a conceptual space (Roschelle & Teasley, 1995) as opposed to traditional cognitive perspective on problem solving that suggests problem solving activity takes places in an individual's mind.

In the context of a problem solving activity, social interactions occur during the shared conception of a problem constructed to attain convergent meaning through communication and action displayed by the team members (Sarmiento & Stahl, 2008). Fundamental activities that take place during effective collaborative problem solving in relation to achieving convergent meaning include four primary features identified by Roschelle (1992):

> (a) The production of a deep-featured situation, in relation to (b) the interplay of physical metaphors, through the constructive use of (c) interactive cycles of conversational turn-taking, constrained by (d) the application of progressively higher standards of evidence for convergence. (Rochelle, 1992, pp. 235)

To be able to observe the construction of a joint problem space, the interactions between team members should be examined to identify these four primary features (Sarmiento & Stahl, 2008). As explained by Roschelle (1992) the first two features presented above describe the nature of the conceptual change that occurs in the relation of deep-featured situations and theory-constitutive metaphors that team participants develop as a result of the joint problem solving activity. The latter two features describe the mechanisms through which the team members reach the convergence. According to Roschelle (1992), convergence is achieved through iterative cycles of demonstrating, approving, and repairing shared meanings. To confirm the convergence learners apply progressively higher standard of evidence.

In relation to convergent meaning making, Roschelle and Teasley (1995) also viewed joint problem solving as the shared knowledge structure resulting from social interactions in the context of a problem solving activity. The pragmatic structure of the joint problem space is developed when collaborators introduce and accept knowledge into the joint problem space, when they monitor any divergences in meaning, and when they repair those divergences that inhibit shared meaning construction. The structured discourse forms that collaborators use to construct their joint problem space through a combination of talking and actions are considered to fall under five categories: Turn-taking, socially distributed productions, repairs, narrations, and language and action.

This study focuses on observations of language and action because they are key in understanding the mechanisms of the generation of mutually shared knowledge structures. To extend the level of analysis on the generation of shared meaning through interaction, the functional roles suggested by Avouris et al. (2003) and discussed below are also incorporated in the study.

Collaborative problem solving in the context of digital games.

Although there are various definitions of collaboration based on different contexts, in this study collaboration is defined as a synchronous activity in which multiple performers are engaged in working towards a common goal. In the game play context, collaboration is two or more players engaged in playing the same game together to achieve common game objectives. This study examines collaboration between two players sitting together and playing a multi-player video game that has split screen capabilities. The split screen offline multiplayer feature of video games creates a natural setting for face-to-face collaboration, as both players are engaged in the gameplay at the same time and have a chance to interact with each other within or outside of the game environment.

Collaborative problem solving that occurs in a multi-player split-screen digital game has three synchronous components: 1) interactions between players outside of the game as part of the collaborative activity, 2) socio-cognitive processes that allow players to solve problems, and 3) game-play. This study explores the relationship between game-play and collaborative problem solving process through studying the influence of game attributes on interactions between players and on construction of the joint problem space.

As part of the collaborative process, interaction between teammates generally occurs when collaborative players assume one or more functional roles identified by Avouris et al. (2003). The functional roles are exhibited in a digitally shared activity space where learners are allowed to insert entities to create a data model. These roles include “insertion of ideas/item into the shared space,” “proposal of an item/idea/action,” “contestation of the proposal,” “rejection of the proposal,” “acknowledgement of the proposal,” “modification of the initial proposal,” “argumentation on the proposal,” and “testing/verifying of a construct or model” (Avouris et al, 2003). In the game space, similar functional roles are assumed by the players. For example, one player may suggest which move they should make next, and they may be in conflict on whether it is the right move or not. Based on their disagreement they can modify the first idea put forward or implement it. These collaborative roles and any other additional roles (such as explaining the gameplay to their partner) players undertake within gameplay illustrate the degree of participation and level of contribution of the players to the joint problem solving activity. To better understand how the distribution and density of interaction between players can be influenced by the game design, it is important to examine how game elements can shape, change, enhance, and/or hinder these roles. In this study, functional roles identified by Avouris et al. (2003) are adjusted to the gameplay context. For example, *inserting items*, which means inserting an entity or an object to the shared digital activity space, is not applicable to a game environment and is changed to *executing an action*. In addition, a new functional role, *explaining gameplay*, is added to extend the scope of the collaborative roles. The adapted functional roles are referred as game functional roles. The list of functional roles, their meaning, and their adjusted version is presented in the Table 1.

Table 1

Adopting Functional Roles into Game Environments

Functional Roles	Meaning	Game Functional Roles	Meaning	Example
Insertion of the item in the shared space	Action of physically inserting an entity that is part of the problem into the shared digital space.	Execution of an action (E)	Executing a move in the game space.	Action: Player 1 avatar walks into another room.
Proposal of an item or proposal of a state of an item or of an action	Communicating an opinion about an entity or a state of an entity.	Proposing a strategy or an action (P)	Communicating an opinion on what action/ strategy should be taken	Message: Player 1 says, “I think we should go into this room.”
Contestation of the proposal	Disputing on a communicated opinion.	Contestation of the strategy or an action (C)	Disputing on a communicated strategy/action.	Message: Player 2 says, “If we go into this room we might get killed quickly.”
Rejection of the proposal	Disagreeing on a communicated opinion or not acting on the proposed opinion.	Rejection of the strategy or an action (R)	Disagreeing on a communicated strategy/action or not executing the proposed strategy/action in the game space.	Message: Player 2 says, “I don’t think so. I am not going to go into this room.” Action: Player 2 avatar does not follow player 1 into the other room.

Table 1 (*continued*)

Functional Roles	Meaning	Game Functional Roles	Meaning	Example
Acceptance of the proposal	Agreeing on a communicated opinion or action of changing the shared digital space based on the consensus.	Acceptance of the strategy or action (A)	Agreeing on a communicated strategy/action or executing the proposed move in the game space	Message: Player 2 says, "Alright that sounds good" Action: Player 2 avatar walks into the other room following player 1.
Modification of the initial proposal	Communicating an idea on modifying an entry or action of modifying an entry in the shared digital space.	Modification of a initially accepted strategy or an action (M)	Communicating an idea to modify a strategy/action or executing a modified version of a strategy/action.	Message: Player 2 says, "I suggest we walk into this room one by one and very carefully." Action: Player 2 avatar takes his gun out and walks into the room through crouching.
Argumentation on the proposal	Communicating the reasons for stated opinion.	Stating a reasoning for a strategy or an action (S)	Communicating the reasons for selecting a strategy/action.	Message: Any player says, "I believe that we should do it my way because…"

Table 1 (*continued*)

Functional Roles	Meaning	Game Functional Roles	Meaning	Example
Test/verify using tools or other means of an object or a construct	Communicating the intent to test the model, or action of testing the model in the shared digital space.	Testing a strategy or an action (T)	Communicating the intent to test the consented strategy/action or executing a consented strategy/action.	Message: Any player says, "Let's try and see if this strategy works." Action: After agreeing on it both player 1 and player 2 avatars enter into the other room.
--	--	Explain how to play the game	Explaining the game controls and gameplay to the partner	Message: Any player says, "Press X to jump across the puddle."

Notes. Functional Roles as identified by Avouris et al. (2003). Game functional roles refer to the adapted role concepts used in this study.

Besides interacting with each other, players also cognitively and socially construct their joint problem space. As described earlier, joint problem space (Roschelle & Teasley, 1995) is a shared knowledge structure built by integrating goals, constructing the current problem state, being aware of possible operators, and identifying the associations between the goals, state, and operators. The verbal, visual and physical interactions between the players are the medium for building the joint problem space. Roschelle & Teasley (1995) concluded that team members use language and action to introduce and accept knowledge into the joint problem space, and to monitor and repair divergence in meaning, in order to successfully construct and maintain a shared conception of the task. In the context of digital games, the association between the functional collaborative roles described in the past paragraph and the socio-cognitive activities that allow players to construct a shared problem space is not thoroughly examined as of yet. Therefore, examining this association and studying the effects of game elements on this association will play a crucial part in this study.

The third important component of collaborative problem solving in the context of digital games is the actual gameplay. Gameplay space consists of the game, the players, the medium the game is played on (game console, PC, etc.), and the interaction between these elements. This study focuses on the game and its attributes in relation to the interactions between the game and the players; and interactions between players. Games consist of many attributes, but only the commonly cited key game attributes that are essential for problem solving processes, such as perceived level of challenge, presentation of rules and goals of the game, and the role of stimuli as feedback mechanism are included in this study.

Level of challenge.

Challenge important component of gameplay; however, the relative appropriateness of the level of challenge to a skill set affects whether an activity or task is enjoyable and achievable (Wilson, et. al., 2009). For people whose skills do not match the challenge level of the activity; the activity might get boring, meaningless, or frustrating (Csikszentmihalyi, 1990). The challenge level should be balanced to within one's capability in order for the activity to avoid being uninteresting (Csikszentmihalyi, 1990). For a game to create meaningful experiences, it should be sufficiently challenging by matching the player's skill set, varying the level of difficulty, and keeping an appropriate pace (Sweetser & Wyeth, 2005). Garris et al. (2002) reviewed game design research and suggested that the optimal level of challenge can be obtained by creating activities that have clearly specified goals with uncertain outcomes, progressive difficulty levels, performance tracking tools, and tasks meaningful to the individual.

The challenge attribute is included in this study because of its close association with the notion of task difficulty that people encounter in any problem solving activity. Within a game context it can be assumed that the task difficulty is a subset of the challenge level of the game since the whole game consists of several tasks. Task difficulty certainly plays an important role in the process of problem solving, and can be adjusted appropriately by the design.

Presentation of rules and goals.

The presentation and communication of rules and goals are an important element of game design. Clearly presented hierarchical goals, and feedback on the progress of goals are likely to result with more meaningful experiences and enhance players' performance (Garris, et al 2002).

Problem-solving activities are enhanced by the presence of goals. The complex cognitive process of problem solving often relies on the following problem solving stages: Identifying the problem, defining the goals, exploring possible strategies, predicting outcomes, and reflecting on what is learned (Woolfolk, 2011). As this general problem solving process suggests, solving a problem starts with clear understanding of the problem and its goal. How game rules and goals are presented may inhibit or enhance the player's understanding of the problem goal. We need to examine the influence of presentation of game rules and goals on players' understanding of the problem goal. By studying how game rule and goal presentation impact interpreting the problem, we can further understand the influence of this game attribute on problem solving outcome and process.

Change in sensory stimuli.

A game player's attention can be captured and altered by visual and auditory stimuli. Malone's foundational work (1980) suggests that the curiosity of game players can be drawn by changing sensory stimuli such as sound effects or dynamic graphics. Sensory stimuli may also play an important role in the learning process as a feedback mechanism. Gameplay requires constant feedback from the system to the user for a healthy interaction and sensory stimuli provides this feedback most of the time.

For effective problem solving, the learners also need feedback. In other situations this feedback may not be provided by change in the colors or audio, but in a digital game context, the process of solving a problem can be facilitated by appropriate sensory feedback.

Research Questions

The overarching question posed in this study is: How does the design of games influence collaborative problem solving processes? Based on the game attributes explored previously, this question can further be explored using three sub-questions:

Question 1: How does the perceived level of challenge in a game influence the collaborative problem solving process?

Question 2: How do sensory stimuli elements provided in a game influence the collaborative problem solving process?

Question 3: How does the presentation of game rules and goals influence the collaborative problem solving process?

Each research question is further broken down to several sub questions, forming specific questions related to functional roles and joint problem space. The relevance and importance of these research questions and the specific sub-questions are discussed in the following paragraphs.

Question 1: How does the perceived level of challenge in a game influence the collaborative problem solving process?

Challenge refers to the appropriateness of the challenge level of the game activities for the player's skills (Csikszentmihalyi, 1990; Garris et. Al. 2002; Sweetser & Wyeth, 2005), and it will be included in this study due to its close association with the notion of task difficulty that game players encounter in any problem solving activity. The second set of questions under this category as follows:

- How does the perceived level of challenge influence degree of participation?
- How does the perceived level of challenge influence the contribution of group members to the developed solution?
- How does the perceived level of challenge influence the density of interaction?
- How does the perceived level of challenge influence construction of shared understanding of the problem goals?
- How does the perceived level of challenge influence the identification of states, operators, and the associations between them?

Question 2: How do sensory stimuli elements provided in a game influence the collaborative problem solving process?

Sensory stimuli can play an important role in the problem solving process as a feedback mechanism and in the collaboration process as a catalyst; and therefore, needs to be included in the study for thorough exploration of these important roles.

- How do sensory stimuli elements influence the degree of participation?
- How do sensory stimuli elements influence the contribution of the group members?
- How do sensory stimuli elements influence the density of the interaction?
- How do sensory stimuli elements influence the construction of the shared understanding of the problem goals?
- How do sensory stimuli elements influence the identification of states, operators, and the associations between them?

Question 3: How does the presentation of game rules and goals influence the collaborative problem solving process?

It is been suggested that clearly presented hierarchical goals, rules and feedback on progress towards goals are likely to result with more meaningful experiences (Garris et. Al. 2002; Sweetser & Wyeth, 2005) and may enhance players problem solving performance. For that reason, it is important to explore the empirical implications of this attribute on players' shared understanding of the problem goal and their collaborative problem solving process.

- How does the clarity of the presentation of game rules and goals influence the degree of participation?
- How does the clarity of the presentation of game rules and goals the contribution of the group members?

- How does the clarity of the presentation of game rules and goals influence the density of the interaction?
- How does the clarity of the presentation of game rules and goals influence the construction of the shared understanding of the problem goals?
- How does the clarity of the presentation of game rules and goals influence the identification of states, operators, and the associations between them?

Rationale and Significance of This Study

Using digital games to support collaborative learning is becoming a popular approach in educational settings such as higher education (Kim & Bonk, 2006) and K-12 education (New, 2010). To meet this increasing demand, better designed games that will provide effective collaborative learning environments are required. Currently the educational game field does not have sufficient amount of research to draw on how to design games that will cultivate learning, problem solving (Kiili, 2007), or collaboration (Zagal et al., 2006). As a first step to provide a solution to this problem, we have to better understand the design elements playing a role in making digital games more effective collaborative learning tools. It is important that we understand the mechanisms behind how these games can foster or inhibit components of collaborative learning. This study fills a gap in the literature on understanding how the design of the games influences the collaborative learning processes in order to improve the design of these games and provide more meaningful learning experiences.

The results of this study will inform educational game design, instructional design, and other fields that are concerned with interactive multimedia design in the context of collaborative learning. This study will not only contribute to the knowledge on effective design of collaborative educational games but also provides insights on how and what types of games attributes promote collaborative problem solving. In a more general sense, understanding the influence of game design attributes on collaborative learning can enhance the design of any collaborative technology-based instructional environment.

Operational Definitions

Games: A game is a complex system that challenges users' intellect through interactions with its structured, rule-defined environment that contains problems and tasks allowing users to learn new knowledge/skills or practice existing knowledge/skills. A main distinction of games is made based on the environment that the game is played on: Board games are played on tabletop boards, whereas digital games are played through digital means such as computers, hand-held devices, and game consoles.

Video Games: Video games, which can be considered a subset of digital games, are defined as the electronic games that are displayed on a video screen or TV. Video games are generally played through using *video game consoles,* which are computer systems specialized in processing and displaying 3D graphics. They allow users to interact with objects on the screen using handheld input devices (controllers). Examples of video game consoles include Play Station, Xbox, Nintendo, etc. Video Games are also distinguished by the genre they belong to.

Multiplayer Video Games: Video games that allow more than one player to interact within the game are referred as multiplayer video games. These games might promote collaboration, co-operation, and/or competition. Players can interact online through servers set up by the game companies, LAN connections by connecting the individual game consoles to the same network, or offline while being in the same physical space and using two controllers hooked into the same game console. Throughout this paper, video games that provide side-by-side collaboration will be referred as offline split-screen co-op multiplayer video games, or co-op video games for the sake of brevity. This study will incorporate co-op video games to provide an ideal environment for collaboration during a problem solving process while disregarding any possible complications that might be caused by online interactions.

Feedback: Word definition of feedback means information that is provided on the result of one's efforts (Slavin, 2012). In the education field, feedback is referred to the information that students receive on their actions and performance. Feedback can be informative or simply motivational (i.e. positive reinforcement). In the context of problem solving, informative feedback is used to provide information about the appropriateness and efficiency of the learner's solution to a problem (Smith & Ragan, 1999). In video games, feedback can be conceptualized in two ways. In a technical sense feedback in video games as digital systems may mean a return of a process output based on input (e.g. Player presses a button on the controller and his game character responds with jumping). However in this study, feedback is referred close to the educational definition. Feedback in video games is defined as the information that players receive in the game world based on their actions in the game. Feedback may include information regarding the appropriateness of their performed actions in the game world. This kind of feedback generally is dictated by the operational rules of the game and informs players about the possible actions that they can perform in the game world. Feedback can also inform the players about their progress towards the goal state.

Feedfront: Feedfront, a term introduced by this study, refers to the information that the players receive in the game world before they performed an action related to solving the problem. Feedfront can be informative or directive. Examples of informative feedfront in a video game may include signs that provide general information about game objects and possible actions, or music/sound that can change to inform proximity of an enemy. This kind of feedfront allows players to understand the problem space before they start solving the problem. Directive feedfront are more straight-forward in guiding the player towards the right solution. Examples of this may include arrows pointing at game objects, directions given in a text format, or distinct colors of objects that indicate a possible learned interaction. This kind of feedfront helps players to identify problem states and possible actions by focusing their attention on objects or actions essential for the solution.

Format and Overview of This Study.

This dissertation contains eight chapters. The first chapter briefly introduces the intent and the context of this research. During the second chapter, an extensive overview of the existing literature is provided. Third chapter informs readers about the study design and data collection methods of this study. The results of this study are presented in three chapters based on the three games utilized. Chapter four highlights the analysis results for *Portal 2*. This chapter contains case analysis results of group 1, group 2, and group 3. Chapter five provides the results for *Indiana Jones 2: The Adventure Continues*. This chapter presents the results of two cases, group 1 and group 3. The last results section, chapter six, contains the results for *Borderlands*. This chapter reports the results of two cases, group 1 and group 4. In the seventh chapter, the researcher discusses the findings of this study. Finally chapter eight concludes the study and provides discussions on the implications of this study.

Chapter 1 Summary

This chapter briefly discussed the gaps in the existing literature on the intersection of digital game studies and collaborative problem solving to state the problems that we are facing today and to layout the foundation for this study. To provide a better picture, this chapter also provided a conceptual framework that was founded on a combination of relevant theories and educational constructs. Conceptual framework of this study was built upon following concepts Jonnasen's (2000) taxonomy of problems, Rochelle & Teasley's (1995) joint problem space, Avouris et al.'s (2003) functional roles of collaborative agents, and literature on game design attributes.

On the basis of this conceptual framework and gaps in the literature, the research questions of this study were formed. The main question that this study is trying to answer: "How does the design of games influence the collaborative problem solving process?" is explored under three sub questions: 1) How does the perceived level of challenge in a game influence the collaborative problem solving process? 2) How does the presentation of game rules and goals influence the collaborative problem solving process? 3) How do sensory stimuli elements provided in a game influence the collaborative problem solving process?

In the next chapter a review of the literature on game design and collaborative learning is presented to provide further evidence for the importance and necessity for this study and to provide a more detailed background that establishes the theoretical framework of this study.

Chapter 2 – Literature Review

In the previous chapter, the researcher established a gap in the intersection of digital game studies and collaborative problem solving literature. From that a set of research questions were formed to lay out the foundation of this study. In this chapter, the researcher further explains the empirical and theoretical evidence that supports these research questions.

The review of the literature begins with the overview of why and how digital games became a prevalent part of our lives. Then, the review continues to explore the role of digital games in the context of education. Empirical and theoretical studies existing in the literature highlights the possible psychological, sociological, academic, and cognitive effects of digital games. After that, an overview of game design attributes is provided to lay out their importance to understand the mechanism that makes games highly engaging. The second part of the literature review explores the concept of collaborative problem solving and the role of technology in creating collaborative learning environments. The researcher also provides a review of the existing roles of digital games in supporting collaborative problem solving. This review concludes with providing further evidence for the need to study the role of multi-player games in collaborative learning processes.

Why Digital Games?

Playing digital games, once defined and considered as a leisure activity just for kids, is becoming a prevalent type of entertainment for people of any age including teens and adults. The numbers presented in the Education Database Online summarizes this craze the best:

> Video games have become quite popular over the last 30 years, so popular in fact that that fully 65% of American households play video games and this number is growing…Of that 65% of the US population, 18-49 year olds make up the largest percentage of gamers at 49%. In times past, it was assumed that the gaming population was children under 18 but today they only make up 25%, perhaps more surprising is the fact that there are more people over 50 that play than children at 26%. The average age of a gamer is actually 32 years old (Education Database Online, n.d.).

After digital games rapidly became a significant part of our lives, their engaging and captivating nature began to puzzle and preoccupy scholars. It did not take too long for the practitioners and scholars to consider the notion of utilizing this highly pervasive and motivating tool in education (Squire, 2003). Although the importance of play for children's cognitive development has been a widely accepted concept (Bruner et al., 1976; Piaget, 1962; Vygotsky, 1978) for centuries, using digital games in education had a troublesome point of entry due to the violent nature of some popular video games and misconceptions about the negative influence of video games. Recent studies about the roles and effects of digital games helped overcome this bad reputation, and opened up a new realm of research on how to make use of these next generation learning environments. Even more recently, the instructional design field started to pay attention to this handy teaching tool because of its capability to provide interactive, engaging and authentic learning experiences for students.

What We Learn From Games: Educational vs. Instructional

Social cognitive theory suggests that learning occurs through interacting with the environment and other people; and it can be explained as the mental acquisition that is a result of our observations (Ormrod, 2008). We interact with others and with our environment on a daily basis from the day we are born till the day we die. Therefore as part of our daily lives, we are exposed to experiences that allow us to learn. Most of the learning happens in informal settings (Smith & Ragan, 1999). Smith and Ragan (1999) used the term *education* to describe all of the experiences we learn from. When the delivery of these specific educational experiences becomes intentional then, it is called *instruction* (Smith & Ragan, 1999). According to this logic, can we claim that all games are educational, but not always instructional? Games provide their users with rich and diverse experiences without the intention of teaching. Although unsystematic, many good commercial games already embody sound learning principles (Becker, 2006). Therefore, from this point forward, a distinction between instructional games and educational games will be made. Instructional games will refer to the games specifically designed to facilitate learning towards pre-identified goals, whereas educational games will refer to all the digital games that encompasses incidental, informal, and formal learning. This categorization makes the assumption that educational games also include all popular commercial games.

After establishing the fact that commercial games can be educational, the following sections will deal with how games affect learning and what type of learning might occur as a result of playing games. It is important to note that while many of the educational research literature deals with instructional games, literature from game design and development community focuses on the commercial games.

Effects of Digital Games: Do We Learn as a Result of Playing Games?

In the short history of their existence, the effects of digital games have been examined through different lenses by researchers from various disciplines. While fields of Psychology and Sociology focused mostly on the impacts of playing video games on children's academic performance (e.g. Benton 1995; Colwell et al. 1995; Roe and Muijs 1998) and aggressive/violent behavior (e.g. Anderson, 2004; Gentile et al.,2004; Griffiths 1999); educational researchers were interested in examining the effectiveness of digital games as teaching tools. Randel, Morris, Wetzel, and Whitehill (1992) reviewed the literature from 1963 to 1991 that compares the effectiveness of instructional games (mostly simulation games) to conventional instruction and discovered that out of 67 studies, only 22 of them favored games (Randel, Morris, Wetzel, & Whitehill, 1992). They also concluded that when very specific content is targeted, gaming tended to show more beneficial outcomes (Randel et al., 1992).

Negative socio-psychological effects of games that were found in the literature created a bad reputation for video games, and spawned pessimistic and suspicious views about digital games in scientist and general public (Ferguson, 2007; Ferguson, 2010; Kutner & Olson, 2008). Although contradictory research results still continue the debate on whether the violence in games increases violent behavior (Anderson & Bushman, 2001; Anderson, 2004; Youssef et Al., 2013), or whether spending too much time playing games causes poor academic performance (Ip, Jacobs & Watkins, 2008; Jiang et Al., 2013), educational scholars looked beyond these negative impacts and tried to understand how games can be useful. One of the strong advocates of gaming research in education, Gee (2003), argued that we have a great deal of principals to discover about learning from good digital games. Other educational researchers suggested that motivational powers of digital games should be harnessed to make traditional education more engaging (Dickey, 2005; Squire, 2003). These conceptual agendas drove many enthusiastic and skeptical researchers to conduct more empirical studies to understand how digital games can be used in education.

Additional studies indicating the possible positive influences and benefits of digital games for learning have emerged in the 21st century. The focus shifted from studying whether games are better instructional tools than other instruments, towards understanding the effects of digital games on specific skill sets. Other studies examined the effects of instructional games in relation to teaching academic content. An evaluative research study examining the impact of a multi-player digital instructional game, Quest Atlantis, revealed that students who used Quest Atlantis showed significant learning over time in science and social studies (Barab, Dodge, Jackson, & Arici, 2003). This study also indicated that students showed increased academic self-efficacy and engaged behavior (Barab et al., 2003). In another study, Dondlinger and Barab (2008) utilized a game-like multi-user virtual environment, Anytown, to understand the effects of digital learning environments with game elements on writing skills. The results from this study also indicated increased motivation towards writing and improved writing achievement scores (Dondlinger & Barab, 2008). Studies on the effects of digital games on Math skills were widely encountered during the review of the literature (e.g. Sedig, 2008). It was stated that players not only demonstrate increased motivation towards the subject (Sedig, 2008), but also show significant improvement in their knowledge of the subject (Sedig, 2008).

In addition to academic knowledge and skills, digital games are proven to be beneficial for obtaining other types of learning outcomes such as problem solving skills (Rosas et al., 2003; Van Eck, 2006), cognitive strategies (Wilson et al., 2009), attitudinal changes (Squire, Giovanetto, Devane, & Durga, 2005), and psychomotor skills (McFarlane, Sparrowhawk, & Heald, 2002). Studies about the effects of digital games also indicated that gaming fosters the development of specific 21st century skills such as decision-making, collaborative work, and creativity (Aguilera & Mendiz, 2003). Games are also known to be used to train and teach interpersonal and intercultural communication principals and skills (Raybourn & Waern, 2004).

After it was established that there are in fact benefits to using digital games for educational purposes, gaming research started to branch out to several grounds. How to design efficient games, how games work, and how to effectively use games in classrooms, etc. were among the frequently encountered research areas. Because the focus of this study on the design of digital games, in the next section, a detailed review of literature on how to design effective educational games will be presented.

Designing Educational Games: Entertainment vs. Instruction

While some scholars in the instructional design field discussed how we can make educational use of available commercial games, others looked at how to design educational games. During attempts to understand the best ways to design educational games, many scholars came across a similar dilemma on how to produce an effective instructional product that is highly entertaining at the same time (Gunter, Kenny & Vick, 2007; Kirkley & Kirkley, 2005; Malone, 1981; Rieber & Noah, 2009; Sedig, 2008). During its evolution to become more appropriate for educational purposes, digital games started to lose their engaging and fun appeal (Van Eck, 2006). This predicament caused scholars to center their attention on the elements of engagement while designing educational games.

Game Attributes: Elements of Engagement

The underpinnings of engaged learning is supported through both constructivist and cognitivist literatures (Dickey, 2005) either through research on cognitive engagement in relation to motivation and learning (Schlechty, 1990), or through examining social participation (Ainley, 2004; Dickey, 2005). Student-centered pedagogy that lies at the heart of the socio-cognitive learning approaches imposes engagement as an essential component of active and meaningful learning (Ainley, 2004; Bruner in Ormrod, 2008; Dickey, 2005). Strategies that put the students at the center of instruction aim for motivated individuals (Becker, 2007) and encompass the belief that people learn best when engaged in an activity or a topic (Norman, 2004; Norman & Spohrer, 1996). Although it is difficult to engage students in academic tasks and formal instruction (Becker, 2007), successful digital games are proven to be capable of engrossing large communities with not too much effort.

How digital games are so successful at engaging the players in the gameplay has been a question of interest for many researchers. Digital games succeed in engaging players of all ages through variety of strategies and techniques (Dickey, 2005; Squire, 2003) employed during the design process.

Due to the multi-faceted nature of engagement and different backgrounds of educational game researchers, in the educational games research field, the term "engagement" is referred to in various ways. Malone (1981), Kirkley and Kirkley (2005) talk about fun and intrinsic motivation, whereas Cordova & Lepper (1996), Gunter, Kenny and Vick (2007) discuss engagement. Other researchers, such as Barab et al. (2005), and Becker (2005), talk about the combination of engagement and motivation. The origins of concepts of fun, engagement, or motivation in games lead us to another phenomenon: immersive play (Becker, 2005). Games provide immersion experience that result with the Flow state, modeled by Csikszentmihalyi (1990) to explain the enjoyment in any activity. Flow state can be considered as being in a state of focused concentration, loss of self-consciousness, or distortion of temporal experience (Sherry, 2004). An activity can generate an immersive and enjoyable experience when people are in a flow state. For digital games, being in a flow state matches to being intensely engrossed and immersed in the gameplay.

Affective aspects of digital games that are accepted as valuable attributes lead scholars and educators to look more closely into gaming. In addition, it is been suggested that we should try to understand how games are exceptional at engaging players and adopt some of the design strategies into instruction (Dickey, 2005). Scholars also investigated the individual characteristics of digital games that were believed to induce engaged and motivated behavior (eg. Juul, 2003; Garris et al., 2002; Malone and Lepper, 1987; Sweetser & Wyeth, 2005; Wilson et al., 2009). These individual game characteristics, generally referred as game attributes, provide a way to scrutinize games at a sub-level that allows us to glimpse into the mechanism, which makes games highly engaging. Although, a large number of attributes are mentioned, review of the gaming literature suggests that the following predominant game attributes promote engagement in games:

Fantasy.

Developing a fantasy story line that allows players to immerse in a different world is a strategy that is used in many successful commercial games. In educational games, the balance between the fantasy world and its relevance to real life should be considered more carefully (Gunter, Kenny, & Vick, 2007). Providing an authentic learning environment can be hindered by the fantasy world that a game exposes to the players, but at the same time, not providing fantasy might make the game less engaging.

This is one of the points where objectives of instructional design clashes with the objectives of entertainment. In cognition theory, it is argued that meaningful and rich learning occurs when a learner is presented with authentic experiences (Brown & Duguid, 1989; Cognition and Technology Group at Vanderbilt, 1992; Duffy & Jonnasen, 1992; Savery & Duffy, 1996) and digital games can provide the representation of the real situation in a virtual environment. Inserting fantasy into a game will reduce the game's closeness to reality and may lessen the educational value of it, but may result with increased motivation. Alas there is not enough empirical evidence on how the fantasy element in instructional games influences learning. While some of the scholars in the field suggest that the game should have environments familiar to the players to foster learning in an authentic way (Warren, Dondlinger & Barab, 2008), others see fantasy as an important element that motivates players (Malone, 1980; Wilson et al., 2009).

When agreed that there should be some level of fantasy in educational games, then our next concern should be how much fantasy is good enough. It is desirable that the level of fantasy should be balanced. One strategy to keep the fantasy at the desired level can be designing the shared context of the game as a fantasy story, and allowing players to do tasks or take quest that can be easily related to real life. For example a MUVE, Quest Atlantis provides a mythological context as the environment's overarching story line in which players are asked to complete meaningful quests. Also, extending some quests to real life activities may help students connect what they learn from the virtual fantasy world to reality. Quest Atlantis takes this approach by requiring players to take part in real life activities such as conducting field studies or interviewing people, in order to complete the quests in the virtual world (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005).

Challenge.

A challenging activity can be an important component to stimulate human beings towards achievements. However the appropriateness of the challenge for skill sets is an important aspect that makes an activity or a task more enjoyable (Amory 2007; Garris et al., 2008; Malone, 1980; Sweetser & Wyeth, 2005). In any engaging activity, the challenge level is balanced to act with one’s capacity (Csikszentmihalyi, 1990). If we want the games to create enjoyable experiences, then they should be sufficiently challenging, match the player’s skill set, vary at the level of difficulty, and keep an appropriate pace (Amory 2007; Sweetser & Wyeth, 2005). Ebner and Holzinger (2007) also talks about the importance of the optimal complexity of a game which generates curiosity and promotes learning. Providing clear and focused goals (Dickey, 2005) with uncertain outcomes (Ebner & Holzinger, 2007) and options given to players can help set the optimal challenge level in respect to the audience of the game.

Sense of control.

There is a common agreement on the necessity of establishing sense of control for players. Literature reveals that feeling control over the game promotes higher levels of enjoyment, engagement, and motivation (Ang & Rao, 2008; Dickey, 2005, 2007; Sweetser & Wyeth, 2005; Warren, Dondlinger & Barab, 2008;). Games can set this up by allowing players to have control over their character development throughout the game (Dickey, 2007; Sweetser & Wyeth, 2005), or by making them feel that they can choose their interactions, actions, or strategies in the game (Sweetser & Wyeth, 2005). Permitting players to personalize the game also create a sense of control. When learners are given an option to personalize the context and amount of practice, it is expected that they show greater motivation (Cordova & Lepper, 1996; Dickey, 2007). Choice is an important aspect that supports this feeling of having control over the game (Dickey, 2005). Some MUVE or MMORPG environments accomplish this by providing multiple quests or free choice tasks (Warren, Dondlinger & Barab, 2008) and empowering the player with the control over how they want to complete the quests (Dickey, 2007).

Social interaction.

In order to engage learners in more effective and meaningful learning experiences, educational games include means of collaboration and social interactions (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Dickey, 2005, 2007; Klopfer & Squire, 2008; Sweetser & Wyeth, 2005; Warren, Dondlinger & Barab, 2008). Generally a structure is provided through the game's narrative or rules to generate collaboration (Papastergiou, 2008). Chat, email, and telegram (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Dickey, 2007; Warren, Dondlinger & Barab, 2008) options are widely used tools that create a collaborative game environment between players. In addition to built-in options that allow players to interact within the game, outside collaboration or social interaction can be founded through external support tools such as personal web pages for each individual (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Another way that games generate social interaction is by simply playing the game with a group of friends – competing or collaborating to complete the game. Players enjoy interacting and spending time together with friends (Sweetser & Wyeth, 2005) and the notion of playing games with friends is considered as one of the main reasons why people play games (Lazzaro, 2004).

Curiosity.

Malone (1980) defines curiosity as the motivation to learn. He talks about two types of curiosity: Sensory and cognitive. While sensory curiosity is achieved through drawing game players' attention with the changes in the sensory stimuli, cognitive curiosity is acquired when a learner realizes that their existing knowledge is incomplete (Malone, 1980). Although the effect of sensory stimuli will wear off quickly, Malone (1980) states that providing feedback and guidance through appealing to sensory curiosity does not require a long attention span and might prove beneficial under certain circumstances.

Visual and audio effects in computer games that are being used as decoration can also appeal to sensory curiosity. As the advancement in current technologies allows commercial games to provide almost perfect graphics and visuals, the players began to have higher expectations from educational games' interface design. Although some simple but essential strategies such as using bright colors, changing colors and patterns throughout the different levels of games, or providing background music (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Sedig, 2008) are used as sensory stimuli elements to keep low budget educational games entertaining and motivating, there is not enough information on how much of game graphics can be tolerated to keep the game still engaging but within the budget.

Rules and goals.

Not to be confused with instructional goals and objectives, digital games often direct and constrain the gameplay with rules and goals that are embedded in the design of the gameplay. Games, by many definitions, are comprised of rules and goals. Rules are considered as the established criteria on how to win (Wilson, et. al., 2009) and how to play the game. Goals are considered as intentions of actions (Locke & Latham, 1990). Well-defined rules and guidelines are an essential part of the game (Wilson, et. al., 2009). While game rules and goals should be clear and well defined, they must still allow players to execute a range of actions (Garris, et al, 2002).

The goal structure of a game is defined by its rules (Garris et al, 2002). There are different types of rules (Crookall & Arai, 1995): System rules, procedural rules, and imported rules. System rules define the operation of the world that is embodied by the game. Procedural rules define actions that can be taken within the game. Imported rules are common sense rules those that participants import into the game from the real world that allow play to take place. Games are fun because sometimes they allow the imported rules to be loosened (Garris, et al, 2002).

Collaborative Problem Solving

Constructivist philosophy argues that learners individually and socially construct knowledge through interpreting their experiences (Jonnasen, 1999). In a similar notion, the social cognitive theory of learning also acknowledges the importance of meaning making in a social context while emphasizing the role of cognition as well (Ormrod, 2008). Both constructivism and social cognitive theory promotes active, constructive, and authentic learning through strategies like collaboration, modeling, and discovery. In the last few decades, several instructional methods have emerged based on these two closely related conceptions of learning, including but not limited to problem-based learning, project-based learning, case-based learning, cognitive apprenticeship, anchored learning, generative learning, and inquiry-based learning.

Problem-based learning (PBL) that arose as a prevalent instructional approach in recent years (Hmelo-Silver, 2004) grew out of medical education practice (Ormrod, 2008; Woolfolk, 2011). In problem-based learning, learners are provided with a carefully constructed problem scenario (Savery & Duffy, 1996) that intrigues their interests and allows them to collaborate (Woolfolk, 2011). Learners are expected to develop flexible knowledge that can be applied in any situation through identifying and analyzing the problem and generating hypothesis about the solution (Woolfolk, 2011). Other expected outcomes of problem-based learning include enhanced intrinsic motivation, problem solving skills, and collaboration (Woolfolk, 2011). Research on problem-based learning reveals mixed results. Hmelo-Silver (2004) reviewed the existing literature to examine the empirical evidence that supports problem-based learning. Her analysis indicated that PBL learners demonstrated increased flexible knowledge, and developed problem solving skills (Hmelo-Silver, 2004). However, her research also showed that there is a lack of evidence to support whether PBL enhances intrinsic motivation, and develops collaborative learning skills (Hmelo-Silver, 2004; Wijnia, Loyens & Derous, 2011). Dochy, Segers, Bossche, and Gijbels (2003) conducted a meta-analysis to understand the effects of PBL on learners' knowledge and skills. They found that while PBL has a positive effect on gaining skills, negative impact was determined when considering the effects of PBL on gaining knowledge (Dochy, Segers, Bossche, & Gijbels, 2003). In an earlier meta-analysis of medical research, Vernon and Blake (1993) found that PBL significantly influenced the learners' attitudes towards the program and increased the measures of their clinical performance, whereas students' factual knowledge and performance on tests measuring academic outcomes were not affected or negatively affected by PBL (Vernon & Blake, 1993).

Instructional theory of collaborative problem solving (CPS), which builds upon the problem-based learning and co-operative learning literatures, aims to provide valuable guidelines for creating collaborative learning environments to support naturally effective collaborative process that is intuitively developed by learners (Nelson, 1999). The goal of CPS is to maximize natural collaboration and provide active, situated, student-centered learning environments that foster the development of critical thinking and problem solving skills (Nelson, 1999). Instructional design literature suggests that CPS is most appropriate when the content to be learned consists of heuristic tasks that are composed of a complex system of knowledge and skills (Nelson, 1999; Nelson & Reigeluth, 1997).

Collaborative learning, which subsumes collaborative problem solving, has proven to be an effective learning strategy (Dillenbourg, Baker, Blaye, & O'Malley, 1995;

Hausmann, Chi & Roy, 2004). Aside from investigating the effectiveness of collaborative learning, the existing literature contains studies on the mechanisms that explain how learning through collaborative problem solving occurs. Hausman et al. (2004) indicated three potential mechanisms that explain how students learn from collaborative problem solving: other-directed explaining, co-construction, and self-directed explaining (Hausmann, Chi & Roy, 2004). Other-directed explaining appears when one peer explains how to solve a problem to a partner. Co-construction is described as the joint construction of knowledge through elaboration and critiquing of a partner's inputs. Self-directed explaining is expressed as learning from someone self-explaining his or her actions (Hausmann, Chi & Roy, 2004). The results of their study indicated that co-construction of knowledge was the most likely mechanism that explains the potential learning during collaborative problem solving. Other studies also acknowledged the importance of joint construction of knowledge as an important factor of collaborative problem solving process (e.g. Mcgregor & Chi, 2002; Rochelle & Teasley, 1995; Sarmiento & Stahl, 2008; Webb & Palinscar, 1996). In their model of collaborative processes, Webb & Palinscar (1996) identify four essential components, in which co-constructing ideas is a part of. Rochelle and Teasley (1995) analyzed how the co-constructed conceptual space, i.e. joint problem space, is built through shared language, situation, and activity.

Collaboration is often studied by focusing on the interactive processes, such as observing learners' strategies, engaging in argumentation, self-explaining thinking, and providing critique (Mcgregor & Chi, 2002); and it is analyzed based on naturally occurring dialogues (Avouris et al., 2003). More specifically, joint construction of knowledge is studied through examining communicative exchanges (Baker et al., 1999; Rochelle & Teasley, 1995), which is informed by discourse analysis. Avouris et al. (2003) takes a slightly different route in how to study collaboration and shift the center of attention to the objects of collaboratively developed solutions. In the pursuit of describing the interpretation of the actors' (group members) intention in communication, Avouris et al. (2003) proposed examination of *functional roles* in the collaborative problem solving process. Functional roles, which stand for the actors' functions in the interaction, were used to report and analyze the purpose of the action in verbal and written dialogues (Avouris et al., 2003). Their "object-oriented collaboration analysis framework (OCAF)" utilizes eight functional roles defined by the researchers: insertion of ideas/items into the shared space, proposal of an item/idea/action, contestation of the proposal, rejection of the proposal, acknowledgement of the proposal, modification of the initial proposal, argumentation on the proposal, and testing/verifying of a construct or model (Avouris et al., 2003). The researchers used a digital system that provided a shared activity space where learners were allowed to insert entities to create a data model. Functional roles identified - specific to the problem and the environment the problem presented in - were then studied to understand the degree of collaboration and the nature of interaction (Avouris et al., 2003). Avouris et al. (2003) also indicate that OCAF provides information on questions relating to the degree of participation, contribution of the team members to the developed solution, density of interaction, identification of interaction patterns, and identification of strategies used for the solution validation.

Collaborative Problem Solving and the Role of Technology

A shared activity space is also a commonly encountered phenomenon in collaborative learning and constructivist learning literature. Problem manipulation space, which is identified as an integral component of constructivist learning environments (Jonnasen, 1999), or a shared activity space (Avouris et al., 2003), is essential for learners to be actively involved. As Jonnasen (1999) would say: “To be active, learners must manipulate and influence the environment in some way”. Therefore, constructivist learning environments must provide learners with problem manipulation spaces that enable learners to test their manipulations, and receive feedback through changes in what is being manipulated (Jonnasen, 1999). Microworlds (Papert, 1987; Perkins, 1991), which represent simplified models and allow learners to observe and manipulate the model, have been used as educational tools to support constructivist learning goals. Along with microworlds, simulations have also been used to provide manipulable learning environments to students. Besides providing constructivist learning environments, technology was also utilized to promote collaboration. In early the 90s, interest in using computers to support collaborative learning showed a significant increase (O’Malley & Scanlon, 1990; Stahl, Kochmann & Suthers, 2006). In those times, the computer systems were designed for individual use, and this constricted the collaboration to talking about the activity and taking turns with the use of the computer (O’Malley & Scanlon, 1990). Computer supported collaborative learning (CSCL) environments evolved a great deal after the rapid progression of the Internet. Research showed recognition of the power of CSCL over other communication methods. Warschauer (1997) identified five distinctive features of CSCL, which are particular to online interactions, as text-based and computer-mediated interaction, many-to-many communication, time and place independence, long distance exchanges, and hypermedia links (Warschauer, 1997). In CSCL research, technological environments (more specifically computers) are seen as mediators of group interactions and meaning making process, and the focus of these technologies are on encouraging social acts (Stahl, Kochmann & Suthers, 2006). The design of the CSCL environments is still an evolving notion and CSCL research is still in the process of identifying unique features of the available media to understand how they influence the course of meaning making (Stahl, Kochmann & Suthers, 2006).

Collaborative Problem Solving and the Role of Digital Games

Increased use of massively multiplayer online role playing games (MMORPGs) and massively multiplayer online games (MMOGs) (Steinkuehler, 2004; Squire, 2006; Whitton & Hollins, 2008) reinforced the concept of integrating commercial MMOGs or MMORPGs into education (Whitton & Hollins, 2008) and designing educational MMOGs or MMORPGs (Steinkuehler, 2004). Whitton and Collins (2008) stated that collaborative gaming environments have been in use for a long time, especially in the higher education setting, despite their high costs and difficulty of customization. Popular commercial MMORPGs such as World of Warcraft (Bennerstedt, & Linderoth, 2009; Dickey, 2007; Martin & Steinkuehler, 2010; Steinkuehler & King, 2009), Lineage (Steinkuehler, 2006, 2007), City of Heroes (Galarneu, 2005), etc. have been widely researched to understand how they contribute to learning and how they can be integrated into instructional practices. Literature also showcases various examples of designed instructional MMORPGs in a myriad of contexts to support collaborative learning. In an

Australian high school setting, an MMORPG called Rochester Castle was developed to enhance collaborative learning in English and Science domains (Lee, Eustace, Fellows, Bytheway, & Irving, 2005). In another study, an online collaborative and competitive game, the Project Execution Game, was introduced to train undergraduate students on risk management during project execution (Zwikael & Gonen, 2007). Quest Atlantis, a multiuser virtual game environment with a socially-responsive design, was developed to engage children between ages 9 and 12 in educational tasks (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Here are some other examples of multiplayer games designed for specific instructional purposes:

1. Age of Computers is a collaborative quiz game that is framed in a MMORPG structure (Natvig, Line, & Djupdal, 2004).
2. eScape is a multiplayer puzzle game that aims to encourage collaborative problem solving (Hamalainen, Manninen, Jarvela, & Hakkinen, 2006).
3. Lecture Quiz is a competitive multiplayer quiz game in which the players participate using their mobile devices (Wang, Ofsdahl, & Morch-Storstein, 2009).
4. Planet Oit is a multiplayer role playing simulation game that was built to develop knowledge and skills in geology (Saini-Eidukat, Schwert, & Slator, 2002).
5. Virtual Computer is an online multiplayer game that is designed based on inquiry-based learning principals, in which the learners were expected to gain knowledge on computer hardware and peripherals (Tuzun, 2007).

The literature reveals that relatively exhaustive investigation and examination of MMORPGs and MMOGs in the context of collaborative learning has been done. However, there is a lack of rigorous research on the arcade style offline co-op multiplayer games and their potential for supporting collaborative learning. As such, only one research article on the arcade style offline co-op multiplayer games was found. In this article, El-Nasr et al. (2011) examined several arcade style co-op games to understand cooperative design patterns (i.e. specific set of design choices regarding game mechanics) and propose methods to evaluate them. Even though their research provided general design lessons to inform the development of co-op games, there was no indication on how co-op games can support collaborative learning. Therefore, understanding the role and potential of arcade style offline co-op multiplayer games for supporting collaborative learning remains as an untapped area.

Chapter 2 Summary

The point of this chapter was to summarize the contributions of previous scholarly work to identify existing gaps in the literature. Based on this review, it is known that problem solving is an effective learning activity that is used in various educational settings. It is also known that collaborative learning is a successful instructional strategy. We know that commercial games can teach well through means of engagement and motivation, even if they are only teaching how to play the game. Games are also known to foster collaboration. However, we still lack empirical and theoretical evidence in how digital games can foster collaboration and problem solving.

With the support of the literature, I intend to make the claim that commercial games provide rich collaborative problem solving environments that can effectively engage players. Therefore, it is essential for us, as educational researchers and practitioners, to understand the concepts and principals behind how these effective media perform, so we can apply what we learn from commercial games into creating sound educational games. In order to understand the principals behind how commercial games are effective, this study examines three game design attributes that are relevant and essential for collaborative problem solving. This review discusses the relevance and importance of challenge, sensory stimuli elements, and presentation of goals and rules in making digital games effective learning tools. Our understanding of how these game design attributes support collaborative problem solving process is still evolving. This dissertation research aims to contribute to this growing knowledge base.

The following chapter introduces the methods that are utilized in this study. This upcoming chapter includes information about the study constructs, selection of research participation and video games, data collection and analysis procedures, and cross-case study design.

Chapter 3 – Methods

In the previous chapters, the theoretical foundation and the literature that this study is based upon was presented along with the purpose and focus of this study. The main goal of this research study is to explore the ways that the design of digital games can influence the collaborative problem solving processes of players. For that reason, three key game design attributes – challenge, sensory stimuli elements, and goals and rules – were studied in terms of their association with collaboration and joint problem solving activity of two person teams. The previous chapter presented existing studies in the fields of collaborative problem solving and digital games to further iterate the gaps in the literature and to establish a conceptual and a theoretical framework for this study.

In this chapter, the methods based in this theoretical framework and used in this study are presented. This chapter includes information about the study constructs, selection of research participants and video games, data collection and analysis procedures, and cross-case study design.

Theoretical Background and Constructs

This study explores the relationship between game design and collaborative problem solving process through studying the influence of game design attributes on interactions between players and on construction of the joint problem space (Figure 1.)

Interactions between the players were studied by observing the functional roles assumed by the players. As part of the collaborative process, interaction between agents generally occurs when collaborative agents assume one or more functional roles identified by Avouris et al. (2003). These roles include insertion of ideas/item into the shared space, proposal of an item/idea/action, contestation of the proposal, rejection of the proposal, acknowledgement of the proposal, modification of the initial proposal, argumentation on the proposal, and testing/verifying a construct (Avouris et al, 2003). These collaborative roles and any other additional roles players undertake within game-play display an important part in informing us about the degree of participation and level of contribution of the players to the joint problem solving activity. Collaborative problem solving processes were studied in relation to how teams construct their joint problem space.

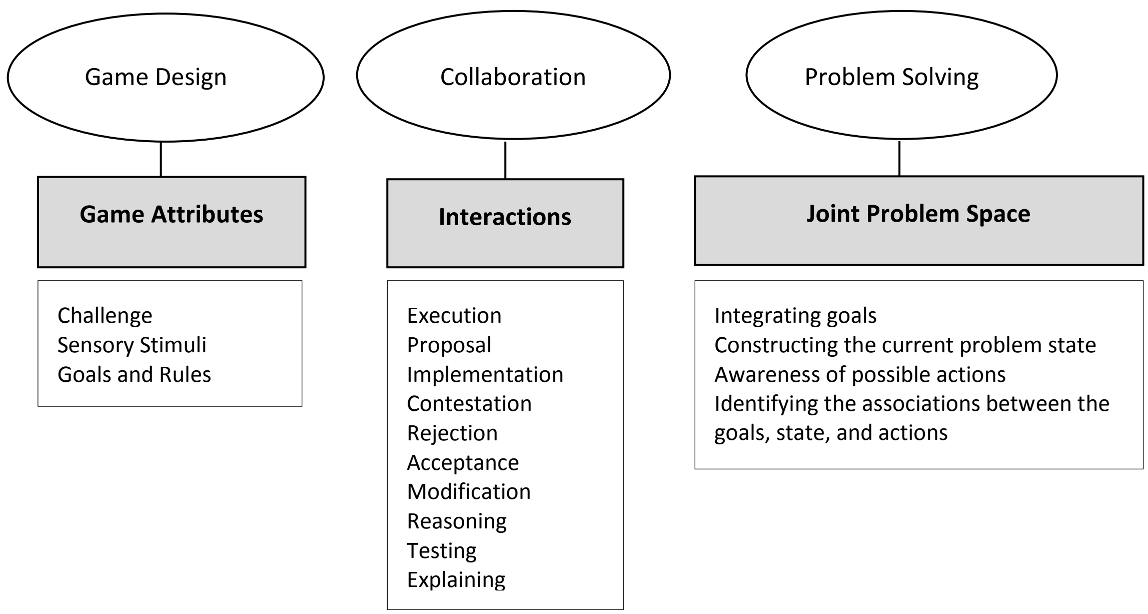

Figure 1. Theoretical constructs and observed constructs examined in this study.

Joint Problem Space (Roschelle & Teasley, 1995) is a shared knowledge structure built by integrating goals, constructing the current problem state, being aware of possible operators, and identifying the associations between the goals, state, and operators. Roschelle & Teasley (1995) concluded that team members use language and action to introduce and accept knowledge into joint problem space (JPS), and to monitor and repair divergence in meaning in order to successfully construct and maintain a shared conception of the task. This study observes the language and action elements that are used to form a shared understanding of the problem.

Research Participants and Games

Selection and Description of the Games.

Thirty-nine offline multiplayer action/adventure video games were identified through a review of the video game literature and through an Internet search of the accessible gaming websites and forums (Scott, J., n.d.; “List of cooperative video games”, n.d.). After identifying the prospective video games, the researcher conducted more Internet research to examine the available pre-recorded game plays and walkthroughs. At the end of the first elimination round, seven games were elected for further analysis based on the criteria provided below:

1. Does the game support collaboration?
2. Does the game provide heuristic tasks and various types of problems?
3. Is the game accessible (old - no longer exists, new - available at market)?
4. Does the game have high ratings? Is it popular?
5. Does it have segmented chapters or missions?
6. What platform it is played on?

After the initial elimination, the researcher obtained the copies of the seven video games (*Borderlands, Portal 2, Indiana Jones 2: Adventure Continues, The Simpsons, Resident Evil 5*, *Resistance*, *Army of Two*) and conducted a systematic game-play analysis. During this systematic game play analysis the researcher played the selected video games to categorize the problem solving activities encountered during the game-play and to identify the essential characteristics of the game that are relevant for this study. The essential characteristics of the game were recorded using the Game Analysis Sheet (Appendix A). Game Analysis Sheet provides a detailed examination of each mission played on five different points: Mission description, task-oriented problem description and type based on Jonnasen's taxonomy (Jonnasen, 2000), how game attributes (challenge and rules/goals) were presented and controlled, and sensory change in the game-play. A table was developed to list all seven games and summarize the criteria that they are judged upon (Table 2).

Table 2

Initial Analysis of Selected Video Games

Games	Nature of Collaboration	Problem Type	Expertise Level Needed	Nature of Sensory Stimuli Elements	Nature of Challenge	Nature of Goal Presentation
Army of Two Rating: 7.9 Genre: Third-person Shooter	Two characters with different equipment mostly required to work together due to the environment and gameplay constrains.	Decision Making Problems Strategic Performance Problems	Intermediate to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Difficult gameplay requiring hand-eye coordination and fast reaction time. Simple problem task.	Mission goals are directly presented verbally and visually as part of the story line.
Borderlands Rating: 8.5 Genre: Action RPG/First-person Shooter	Two characters with different skills and equipment voluntarily work together.	Decision Making Problems Strategic Performance Problems	Intermediate to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Difficult gameplay requiring hand-eye coordination and fast reaction time. Simple problem task.	Mission goals are directly presented verbally and in written text format.
Resident Evil 5 Rating: 8.8 Genre: Survival Horror/Third-person Shooter	Two characters with different equipment mostly required to work together due to the environment and gameplay constrains.	Decision Making Problems Strategic Performance Problems	Intermediate to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Difficult gameplay requiring hand-eye coordination and fast reaction time. Simple problem task.	Mission goals are directly presented verbally and visually as part of the story line.
Resistance 3 Rating: 7.3 Genre: Post-apocalyptic First-person Shooter	Two similarly equipped characters sometimes required to work together due to the constraining game environment.	Decision Making Problems Strategic Performance Problems	Intermediate to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Difficult gameplay requiring hand-eye coordination and fast reaction time. Simple problem task.	Mission goals are directly presented verbally as part of the story line.
Portal 2 Rating: 9.2 Genre: First-person Puzzle/Platform	Two similarly equipped characters always required to work together due to the constraining game environment.	Rule Using Problems	Beginner to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Simple gameplay. Simple to complex puzzles/problem tasks.	Obvious repetitive goals that are hinted through use of sensory stimuli elements.
Lego Indiana Jones 2: The Adventure Continues Rating: 7.6 Genre: Action/Adventure	One main character and several side characters with different skills and tools sometimes required to work together to complete the game levels.	Logical Problems Rule Using Problems Strategic Performance	Beginner to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Easy to difficult gameplay, sometimes requiring hand-eye coordination and fast reaction time. Simple to complex puzzles/problem tasks.	Goals are not presented directly, but hinted through use of sensory stimuli elements.

The Simpsons Rating: 7.5 Genre: Action/Platform	Two characters with different skills and equipment sometimes required to work together due to gameplay constrains.	Rule Using Problems Strategic Performance	Beginner to Expert	Various visual and auditory sensory stimuli used as feedback and feedfront mechanisms.	Easy to difficult gameplay, sometimes requiring hand-eye coordination and fast reaction time. Simple to complex puzzles/problem tasks.	Goals are not presented directly, but hinted through use of sensory stimuli elements.

During the data collection only three games were utilized: *Portal 2*, *Borderlands*, and *Indiana Jones 2: Adventure Continues*. The decision to conduct the research with only these three games of the initially selected seven games was made based on both the games' ratings in the metric and participants' experience and comfort levels with the genre of the game. Three of the initially selected games were first-person shooters, and unfortunately the most of the participants who volunteered to take part in this study did not feel comfortable with playing the first person shooter games.

The three games selected presented problems that covered a range of complexity and structure. The structuredness and complexity of the problems faced during these games is abstractly presented as in Figure 2. It is important to note that the derived structuredness-complexity plot is not a data-driven representation. It aims to provide a conceptual visual representation of the type of problems encountered in a game. This conceptual visual representation is developed based on the combination of the researcher's identification of the problem types in a game and Jonnasen's taxonomy (Jonnasen, 2000). The point of this plot is to provide a visual comparison of prospective problem types between the video games utilized in this research.

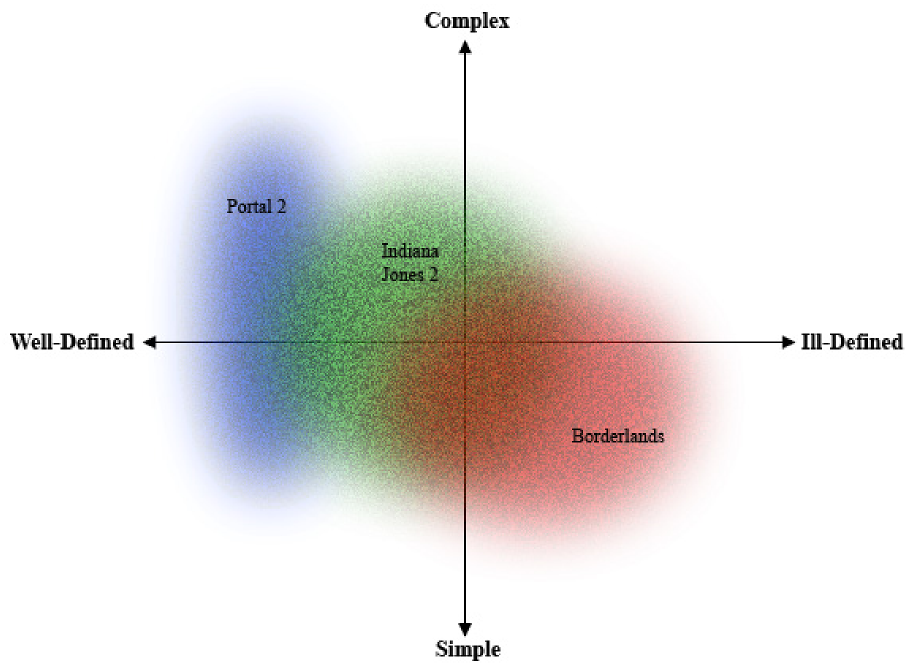

Figure 2. Abstract representation of the problems in the structuredness-complexity spectrum.

Detailed descriptions of each of these games are provided in the following sections.

Portal 2.

Portal 2 is a first-person puzzle platform video game that was developed by Valve Corporation and it was released in 2011. While the single and multiplayer co-op modes offered a similar gameplay, for the purposes of this research, only the multiplayer co-op mode was analyzed and included. The co-op mode compromises a series of puzzles in which the robotic characters Atlas (also referred as Blue) and P-Body (also referred as Orange) are required to collaborate to solve the testing courses designed by GLaDOS, an artificially intelligent computer. Each character is given a portal gun and the main premise of the game is that the players use the portal guns to teleport through inner-spatial portals between two white-colored flat panels (“Portal 2”, n.d.). During the game, players have to place their portal entrance and exit in strategic locations, maneuver through the portals in clever and atypical ways, redirect laser using portal, and launch themselves and objects using the aerial plates, etc.

The co-op mode gameplay starts with the “Calibration” chamber that separates the players in two parallel running rooms and trains them in how to communicate, collaborate, and play the game. After the calibration level is completed, the players come to a central hub which, then, they will keep returning after each level is completed. Each level of the game provides between 6 and 9 different test chambers and the puzzles in each chamber focuses on particular testing element (“Portal 2”, n.d.). The gradually increased difficulty and the progressive introduction of new elements and puzzles in each chamber provide a well-designed and an intriguing gameplay. For this research, only the Calibration and first two levels were utilized. Here is the list of the levels included in this study:

Tutorial level: calibration.

Tutorial session gives players a chance to practice their collaboration skills and game play skills. This part of the game consists of one testing course that resides seven rooms. Each room is filled with various puzzles that gradually introduce obstacles and game entities to the players. One way tutorial chamber differs from other chambers in the game is that even though the players are placed in glass-separated rooms that are mostly identical, they still have to work together to overcome the obstacles and complete the level.

Chamber I: team building.

Chamber I consists of six testing courses that provide various game entities and challenging puzzles. During this chamber, the game tries hone the players' team player skills through providing puzzles that require constant healthy communication between the players. This chamber introduces the simultaneous action taking, such as pulling the wall switches at the same time, or pressing multiple buttons around the same time, while still building on the previously gained skills and knowledge.

Chamber II: mass and velocity.

Chamber II consists of eight testing courses that provide various game entities and challenging puzzles. During this chapter players learn a new game maneuver called flinging, an action that is based on the concept of velocity. Players continue to worked together to solve problems that get complicated as they progress.

Problem solving.

In *Portal 2*, players are repeatedly presented with well-defined rule using problem tasks. The main problem task that players collaboratively deal with in this game is to identifying how to use a combination of elements given in the game (portals, cubes, switches, lasers, etc.) to get out of the test chamber. The end goal of each test is to open the exit door so that players can proceed into the next chamber. Although this game lacks in providing various types of problems, it makes it up with the changing complexity of the task that is given to player in each chamber. The structuredness and complexity of the problems faced during this game is abstractly presented as in Figure 2.

Some of the sub problems that the players deal with during the first two chambers of the game follow as:

- How to obtain cubes that will activate switches.
- Which switches in what order needs to be activated.
- At which strategic points to place the portals to move towards the goals.
- How to divert a laser through using combination of cubes, portals, and jumping points to activate lifts and doors, etc.
- How to avoid getting destroyed by the guard robots.

Sensory stimuli elements.

This game utilizes variety of verbal, visual and textual sensory stimuli elements to provide guidance and feedback for the players. It starts with heavy verbal feedback (through GLaDOS) and textual feedfront sensory elements during the tutorial session to help players learn how to play the game. As the players progress these elements leave their place to more visually heavy sensory stimuli. Here are some of the ways that this game utilizes sensory stimuli elements:

Wall information panels display what kind of actions the team needs to take before each the testing chamber. Dotted lines indicate a relation between two connected game objects, such as a door and a floor button, and changes color as a player interacts with them. Texts appearing on screen give direct information about the game controls e.g. “Press R2 to shoot a portal” text appearing after a player obtains a portal gun for the first time. Figures displayed on floor next to game objects hint the possible use of the object and/or its association with other objects. Examples of this sensory stimuli element include signs that are displayed both under a tower button and over a cube dispenser meaning that if you press that specific button a cube will be released from that specific dispenser, or arrows displayed around a spring board to show the direction that player will go if he/she jumps on it. Distinct colors and shapes of objects indicate certain kind of information, i.e. white walls means places to put portals, an angled white wall indicate a location to shoot out of at the end of a flinging action, transparent cube means that it can be used to redirect laser beams, and red floor button means that a player has to step on it to activate a door or any other game object, etc. Voice of GLaDOS provides confirmatory or corrective feedback as well as building a story line in a sarcastic manner. Ticking noise informs players about the timed events such as a door closing again five seconds after a button is pressed.

Rationale for selection.

Portal 2 is a one of kind co-op puzzle/platform game that does not fail to capture the attention and interest of a player. It does not require expert game play skills such as quick reaction time or precise hand-eye coordination unlike many of the first person shooter games does. Therefore, this game can be enjoyed by wide range people with different skill sets or demographics. This neutral game provides well-defined problems that vary from simple to complex in their natures. Also it successfully incorporates a range of sensory stimuli elements that serve as feedback or feedfront mechanisms.

Borderlands.

Borderlands is a first person shooter/action role playing game that was released in 2009 by Gearbox Software. Co-op mode of this game entails a series of missions that partners complete together to level up and build their characters to get ready to take on more challenges. The open nature of this game world allows players to wander around to any place they would like instead of following the story line that provides them with missions that are gradually increasing in difficulty. Collaboration becomes an optional phenomenon, as one team member might be able to complete the given missions by himself/herself without much help. This game tries to promote collaboration through providing tougher enemies that are too many in numbers than one person can deal with.

Players start the game with choosing one of four characters, and build his/her skills throughout the game through getting experience points by completing missions and killing enemies. As they level up their ability to use available guns gets better and they can carry more number of guns. Throughout the game the players are expected to manage their inventory (backpack), combat with enemies, and loot to find better guns, ammo, and money. As its genre might suggest, this game requires quick response time and precise hand-eye coordination, especially during combat scenes.

Borderlands gameplay provides 48 mission that are part of the story lines and 79 side missions with total of 127 missions. The world of Pandora, the planet where the story takes place, is divided into 10 areas. The game starts at the first area called Arid Badlands after the game characters gets out of a bus. The early moments in the game can be attributed as a training level where the players slowly learn how to play the game as they follow a robot called Claptrap around the large game world. After that, the game introduces more story characters such as Dr. Zed or T.K. Baha that give more missions to the players. Missions in general include objectives such as killing requested number of enemies, finding objects to fix machines, and locating requested objects and bringing them back to their owners, etc. Including the tutorial missions this study only examined the first eight story missions that took place in Arid Badlands.

Problem solving.

While the rule-based problems that the missions provided are not very complex, other open-ended problems that the players face during this game proves themselves more challenging. Aside from the straightforward problems that come across in missions, the players encounters decision making or strategic performance problems such as managing equipment, and sharing resources to maximize efficiency, and identifying and applying tactics to meet strategy during combats. Therefore the problems in this game can be abstractly presented as more towards the ill-defined segment of the structuredness spectrum.

Some of the problems that the players faced during the first eight missions included here:

- How to maintain your gun and ammo inventory.
- How to find your way around the game world.
- How to identify strategies to effectively kill the enemy.
- How to apply the strategy in real-game-time combat.
- Where to find hidden stashes of guns and money.
- What kind of gun to use in what type of situation.
- How to share the resources between players.

Sensory stimuli elements.

Borderlands bombards the player with sensory stimuli elements. A screenshot of gameplay that contains some of the sensory stimuli is presented in Figure 3.

Figure 3. Borderlands sensory stimuli presentation. Visual sensory elements are generously used in the form of HUD (Heads-up display) to provide information about a player's health (2), level (4), ammunition (6), location (4), status of the enemy (1) and progression (5).

In addition, during and before combats player receive various auditory sensory elements such as bandits speaking loudly or music changing to a specific tone which indicates that enemies are close by. During the combat scenes the players receives confirmatory and directive feedback through visual sensory stimuli elements such as points displayed on screen when an enemy is aimed at and shot correctly (3) or a red banner displayed to indicate the direction of the enemy that is shooting at you (7) which also means that the player is getting hurt.

This game also makes use of the pop-up text boxes to provide lengthy information about the game controls and rules for the players. Even though most of the game controls and rules are slowly introduced to the players during the initial missions via pop-up text boxes, textual sensory stimuli elements are still used throughout the game to provide information about the game rules, guns, missions, etc.

Rationale for selection.

This game provides a unique play opportunity through combining RPG features with first person shooter features. While the combat scenes requires expert gameplay skills, the character building and scavenging parts of this game allows people with lesser experiences to get into this game. The openness of the game world was another reason why this game was included in this study. While the teams were asked to follow the story line and complete the missions by the game characters, they eventually had the freewill to do as they wished. The open-ended nature of this game world along with the types of problems that are less structured made this game distinct and an interesting piece to study.

LEGO Indiana Jones 2: The Adventure Continues.

This game, published in 2009 by LucasArts, is a sequel to the original Lego Indiana Jones video game. The co-op version of the game allows players to join in and out of the game whenever they like. This game provides six hubs with stories based on the four famous Indiana Jones movies (Kingdom of Crystal Skull, Raiders of the Lost Ark, The Temple of Doom, and the Last Crusade). The game starts with the Kingdom of Crystal Skull Part 1 hub and as the players progress other hubs gets unlocked. Each hub provides a various number of story levels. This study utilizes one story level (divided up in manageable sections based on cut scenes) in Kingdom of Crystal Skull hub, and three story levels form the Raiders of the Lost Ark hub.

This game provides various game modes combining both fast paced action scenes and low pressure puzzle scenes. For example, in Market Mayhem level the players focus on defeating the enemies, in Map Room Mystery level they solely dropped in a puzzle like environment, and in Raven Rescue level the players solve the puzzle while being in the middle of a fight scene.

Problem solving.

This game incorporates the widest range of problem types including logical problems, rule-using problems, and strategic performance problems. The main problem that the players have to figure out changes every level. While some levels focus on puzzles other levels focus on the action aspect of this game. Therefore, the players alternate between problems like “how to arrange three reflector dishes to redirect a beam at a specific location” to “how to apply and modify strategy during fight scenes.” The problems in this game can be abstractly presented as more in the center of the structuredness-complexity plot due to the variety of problem types it uses.

Sensory stimuli elements.

This game incorporates heavy feedfront visual sensory elements to lead the players towards the solution. A screenshot of the gameplay is provided to present some of the sensory stimuli elements in Figure 4. Most prominent of these feedfront elements are the flashing text displayed on the bottom of the screen that either directly tells player what to do or hints it. This game also utilizes subtle visual sensory elements such as coins suspended in the air to direct players towards the end of the level. Since goals are not clearly displayed using subtle elements helps players to identify where they need to go to proceed in the game. A simplistic HUD (Heads-up Display) is also used to displayed characters' health levels and amount of coins they collected. During the fight scenes HUD is also used to display the enemy information and number and type of enemies that needs to be defeated in order to progress.

Figure 4. Indiana Jones 2 gameplay screen shot that contains sensory stimuli elements. Such as the flashing text displayed on the bottom of the screen that either directly tells player what to do or hints it.

Rationale for selection.

The second Indiana Jones game is another game that could be more easily played by wide range of audiences with varying skills and demographics. Aside from the fact that it has an easy gameplay, this game also does a great job at providing various problem types and complexity by alternating between puzzle and action focused levels. In addition, the prominent use of sensory stimuli elements to guide the players in the problem solving process makes this game different than other selected games.

Selection of the participants and forming the groups.

Six participants were recruited through online advertisement (email list-serves, twitter, Facebook) and flyers distributed around the campus. The demographics and the information relevant to their level of experience with video games were collected through a preliminary questionnaire that was filled by the participants upon his/her first contact with the researcher. The detailed information about the participants can be found in Table 3.

Table 3
Participant Demographic and Gameplay Experience Information

	Teams	Age	Gender	Level of Experience w/Video Games[a]	Level of Experience w/Game Consoles[b]	Level of Expertise (Reported)	Level of Expertise (Observed)	Coop Experience	Types of Games
Tom	Group 1	22	Male	2	2	Intermediate	Intermediate	Yes	Action/Adventure Games, Role Playing Games, Platform Games
Liz	Group 1	23	Female	3	1	Novice	Beginner	No	Other type of games
Amy	Group 2	32	Female	4	8	Intermediate	Advance Intermediate	Yes	Action/Adventure Games, Role Playing Games
Dan	Group 2 & Group 4	19	Male	4	9	Expert	Expert	Yes	Action/Adventure Games, Role Playing Games, Platform Games, First/Third Person Shooter Games, Other Types of Games
Mike	Group 3 & Group 4	28	Male	4	4	Intermediate	Expert	No	Action/Adventure Games, Role Playing Games, First/Third Person Shooter Games
Dale	Group 3	27	Male	3	0	Novice	Beginner	Yes	Role Playing Games, First/Third Person Shooter Games

Note. [a] Level of Experience a/Video Games was derived from questions “3a-Have you ever played or do you currently play video games?” , and “3ai-If yes, how often do you play video games?”. [b] Level of Experience w/Game Consoles was derived from questions “3aiii-Do you own a video game console?”, “3aiv-How comfortable are you with playing games on an Xbox?”, and “3av-How comfortable are you with playing games on a Play Station 3?”.

The participants were paired up to diversify gender and previous play experience with video games. Their common availability was also taken into account during the pairing process. Initially three groups were formed. Each group was informed that they will play three games through three sessions and was asked about their experience and existing knowledge of the games that were on the initially selected game list. However, after the teams’ reactions to the games on the list, a slight change in the design was made to accommodate their experiences. Also two of the groups were divided up and most experienced two players (Mike & Dan) were matched up together to create a new group that would diversify the experience levels of the research groups and allowed a first person shooter game to be included in the study. Based on their reactions to the proposed games, their interest in participating in this study, and their level of expertise with the game genres the teams were assigned to play the video games presented in Table 4 for the study sessions.

Table 4
Gameplay Sessions and Assignment of Participants

	Level of Experience[a]	Games Played			
		Session 1	Session 2	Session 3	Session 4
Group 1 (Tom & Liz)	I+B	Portal 2	Portal 2	Indiana Jones	Borderlands
Group 2 (Dan & Amy)	E+AI	Portal 2	Portal 2		
Group 3 (Mike & Dale)	E+B	Portal 2	Indiana Jones		
Group 4 (Mike & Dan)	E+E	Borderlands			

Note. [a]E: Experienced, AI: Advance-intermediate, I: Intermediate, B: Beginner

A player in both group 1 and group 2 expressed their concerns about playing first person shooter games. Since the level of expertise with video games in general was low for these particular players, asking them to play first person shooter games could have put too much pressure on them. Because of this initially the researcher decided not to use any first person shooter game in the research. However, after a few sessions group 1 player seemed to gain some experience and sounded more confident about playing a first person shooter game. After both players in group 1 expressed their enthusiasm in playing games and participating in this study, a fourth session was arranged for them to play a first person shooter game, *Borderlands*. Meanwhile, the researcher divided up group 2 and 3 and matched up two of the most experienced players to create a new group who can also play the first person shooter game. This way each game was played by at least two teams. Also this allowed the researcher to have a variation in the groups' level of expertise. The other less inexperienced players (Dale and Amy) in group 2 and 3 were also asked to meet for another session, however due to the conflicts in their schedule they were never able to make it.

Data Collection

Data collection took place during fall semester after the IRB approval (Appendix F). The interactions between the players within and outside of the game were video recorded to capture the game-play, the player-to-player interactions, and conversations. Players were also asked to complete a questionnaire after completing each mission or level in the game to measure their perception of level of challenge, and clarity of the game rules and goals. The questionnaire (Appendix C) for this study included relevant sections from Game Experience Questionnaire (developed by IJsselsteijn et.al.) and eGameFlow Questionnaire (developed by Fu et. al.). The following procedures were followed to collect data for each game-play session:

Before the game:

1. Collect demographic data during participant recruitment (through the before-session questionnaire presented in Appendix D).

During the game:

Before the mission starts:

1. Remind the team that this research is interested in their interactions and how they solve the problems together therefore it is important that they verbalize their strategies and discuss possible plans on how to what they think needs to be done.

Throughout the mission:

1. Prompt the team to have a conversation about their game strategies if needed.

At mission break points:

1. Ask participants to fill out the study in-session questionnaire presented in Appendix C.

Data collection instruments.

Two questionnaires were developed and incorporated during this study to collect data during this study. A before-session questionnaire was developed to collect demographic information and participants' skills and experience with gaming. This questionnaire consisted of several questions and sub-questions asking about the participants' age, gender and relevant gaming experiences (presented in Appendix D). The information collected through this questionnaire allowed the researcher to make informed decisions during forming the groups.

The in-session questionnaire consisted of seven questions regarding the players' perception of challenge and six questions regarding the players' understanding of the game goals and rules. It was administered at the break point of each game (mainly after completing missions or game sections). This questionnaire (presented in Appendix C) was developed based on the Game Experience Questionnaire (developed by IJsselsteijn et.al.) and eGameFlow Questionnaire (developed by Fu et. al.). This in-session questionnaire was utilized to calculate the players' overall ratings of the mission challenge levels and the clarity of the goals and rules.

The first five questions (1-a through 1-e) regarding the game challenge was summed up to generate a score for the players' overall rating of their perceived challenge during a mission/section. Although initially the last two questions (1-f and 1-g) of challenge section were considered to be included in the overall challenge rating calculations, this decision was later on changed for the following reasons: Question 1-f asked about if the player felt bored while playing the game and the responses to this question was consistently zero for most cases. Also considering the negative scale, summing this question up with the others did not serve the purpose of this research. Therefore this question was treated as a stand-alone indicator of boredom with the game session. The question 1-g asked players to rate whether the challenge levels were adequate. After more consideration the researcher decided that this question served more of a summative role in the questionnaire and summing it up with others would influence the face validity of the challenge scale generated. In a similar fashion, the last six questions (2-a through 2-f) were summed up to generate a composite score for the players' understating of the clarity of the goals and rules.

The items that generated the composite scores for each construct demonstrated a relatively strong internal consistency. The Cronbach's alpha (Cronbach, 1951) was .86 and .88 respectively for perceived challenge levels and clarity of the goals and rules.

Study Design

A qualitative cross-case study approach was utilized to explore the influences of game design attributes. This qualitative exploratory approach allowed researcher to examine the influential relationships in detail. The cross-case aspect of this study allowed researcher to emphasize the detailed contextual analysis of the possible relationships across different genres of games. Eventually, the selected study design allowed researcher to bring further understanding to a complex phenomenon through identifying possible mechanisms in which game design attributes promote or hinder collaborative problem solving processes.

This three-level cross case study incorporated three video games with varying degrees of problem structure to provide a deep understanding of collaborative game-play and problem solving phenomena in relation to the game design. The first level cases consisted of a combination of a group and a game with a total of seven cases: Game1Group1, Game2Group2, Game1Group3, Game2Group1, Game2Group3, Game3Group1, and Game3Group4. The second level cases were compromised of the selected three video games: Game1, Game2, and Game3. This study started to investigate the relationship between the game design and collaborative problem solving with a focus on the players via thorough examination of the first level cases (within game within group). After that, the focus was changed to the attributes of the games and each of the second level cases (within game across group) were analyzed to get a better sense of the differences and communalities in the influence of game design elements across a group of people who are playing the same game. The final level, cross-examination of second level cases (across game across group), was also utilized to further study the effects of different design elements' on collaborative problem solving process. A graphical presentation of the study design is provided in Figure 5 to better explain the structure of this study.

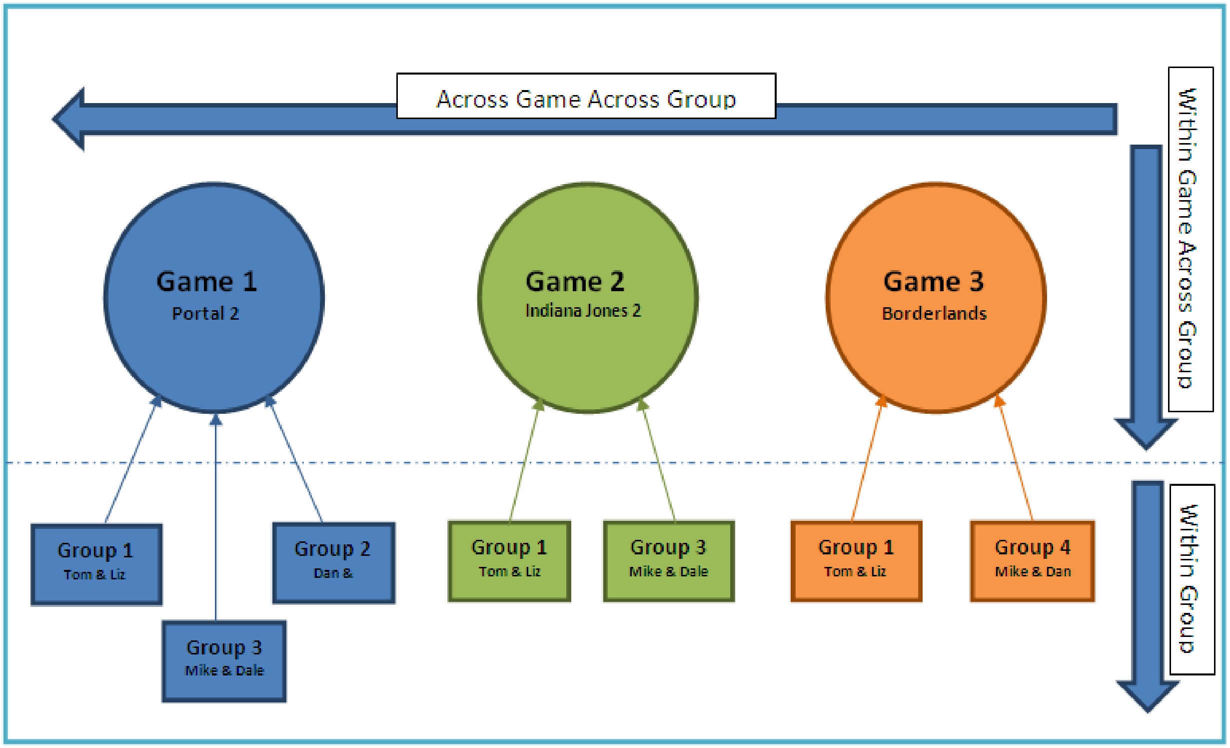

Figure 5. Study design structure.

Data Analysis

Within-case and cross-case analysis methodology (Miles & Huberman, 1994) is employed to inspect the results of this study. Seven first level cases are systematically analyzed to identify the trends and associations in the interactions and how shared meaning of the problem is constructed through the influence of game attributes across the different games that the team played over time. This study also examined the patterns in the influence of game attributes on the collaborative problem solving process across the different cases (i.e. second level cases).

The gameplay recordings were transcribed using an Excel worksheet designed for this study (Appendix B). The worksheet was constructed on the predefined codes that were developed based on the literature that is relevant to the focus of this study. Through an iterative data analysis process additional codes that emerged from the data were also included. A list of codes and their descriptions were provided in appendix E.

The specially designed Excel worksheet (Appendix B) consisted of fields that would allow the researcher to note down data about players' assumed functional roles (e.g. propose, execute), their action in the game (e.g. walk, shoot, activate), the entities that they interacted in the game (e.g. button, robot, switch), feedback/feedfront that correspond to an interaction, their conversations regarding game rules or goals, sensory elements, and joint problem space. Through this method of transcribing, the researcher was able to capture both what was taking place in the game environment and the players' discourse at the same time. The researcher categorized the conversations while transcribing through the use of columns in the excel worksheet. The main category of codes such as conversation about game goals and rules, sensory stimuli, and joint problem space were included as columns in the data analysis excel worksheet. The sub-categories, which are more detailed codes, were applied to the data after the researcher reviewed the excel sheets. This iterative process of reviewing the excel sheets with codes allowed the researcher to further categorize the discourse of the teams and form the structure of the case analysis and write-up.

In general, the analysis focused on whether and how the game design elements influence collaborative problem solving process. In the following sections include the details on how the analysis of each construct was conducted.

Analyzing joint problem space.

The conversations between the participants were analyzed to gain in-depth understanding of how shared understanding of the problem was constructed. The conversational data were coded based on identification of problem states, possible actions, and associations. The discourse was also coded regarding when the players were talking about the game goals.

Analyzing interactions.

The gameplay and conversational data were coded to identify assumed functional roles. The frequencies of the assumed functional roles were counted to achieve information about the distribution and balance of roles assumed during the problem solving activity. The conversations between players regarding functional roles were reported to support the descriptive numbers provided in this study.

Analyzing the influence of challenge.

The data regarding perceived level of challenge was obtained through in-session questionnaires. Each section of the game was rated by the players in terms of the level of challenge that they experienced. These ratings, their conversation regarding constructing a joint problem space, and frequency of functional roles were associated for each section of the game to explain how the level of challenge influenced collaborative problem solving process. Additionally, the reasons that the players felt challenged were characterized in two categories through observing the gameplay and player conversations: challenge due to a complex problem task and challenge due to difficult gameplay.

Analyzing the influence of sensory stimuli elements.

The data on sensory stimuli elements were captured through observing the gameplay. The instances when the sensory stimuli element was provided by the game was noted on the excel sheet. The players’ conversations and actions that were within the close time proximity and were relevant to the occurrences of the sensory stimuli element were associated with the observed sensory stimuli. Relevant conversations and actions refer to the observed language that was an indication of acknowledgement of the sensory stimuli or observed performance of an action that was direct reaction to the sensory stimuli. These conversations and actions were then utilized to establish how the sensory stimuli elements influenced their collaboration and construction of joint problem space. Additionally, the sensory stimuli elements were analyzed in two main categories that were established based on the researchers observation of the gameplay: Feedback and feedfront sensory stimuli elements. A further coding was conducted to identify the function, presentation, and amount of sensory stimuli elements (Appendix E).

Analyzing the influence of game goals and rules.

The data on the game goals and rules were captured through in-session questionnaires. The in-session questionnaire allowed players to rate each section of the game in terms of how clear the goals and rules were. These ratings, the players' conversations regarding constructing joint problem space, and the frequency of the functional roles were associated. Furthermore, based on the observation of the gameplay and players' discourse, the rules were analyzed in two categories: procedural and operational; and goals were analyzed based on their presentation style: repetitive, clear, and vague.

Chapter 3 Summary

This chapter provided an overview of the study design and maps out the methods and techniques utilized to answer three research questions that are focus of this study. To study the influence of game design attributes on collaborative problem solving process, a cross-case study approach was utilized. Cases consisted of three video games and were analyzed at three levels: within group within game, across group within game, and across game.

After the recruitment process, six volunteered participants were formed into groups of two and were asked to attend several research sessions to play selected games. During each research session, visual and auditory data regarding two players that are working collaboratively to complete tasks given in a game environment were captured. Data collection techniques of this study consisted of observations and questionnaires. Through these methods data regarding player interactions and conversations along with their perceived level of challenge and clarity of game goals and rules were obtained over nine research sessions across four groups with switching participants.

In the next three chapters, the results of the within case analysis for the three games, i.e. *Portal 2*, *Indiana Jones 2*, and *Borderlands*, are discussed in detail. Each of these chapters provide an overview of the player collaboration and joint problem space, as well as more specific sections regarding the influence of game design attributes on these constructs.

Chapter 4 – Portal 2

In the previous chapter, I laid out the methodology and techniques used in this research to collect and analyze the data. As indicated earlier, the results of this study will be provided at multiple levels consisting of within and across case analysis.

This chapter includes the analysis of three first-level cases that consist of group one, two and three, as well as a within-game across-case analysis of *Portal 2*. During this chapter, each group's gameplay, conversations, and interactions are thoroughly analyzed to examine the potential relationships between the game attributes and collaborative problem solving process. Within each case, the game chambers were separately analyzed for collaboration, joint problem solving space and the influence of game design attributes on collaborative problem solving process. The results are presented under the three following sections: Within Case 1 – Group One (Tom and Liz), Within Case 2 – Group 2 (Dan and Amy), and Within Case 3 – Group 3 (Mike and Dale).

Within Case 1: Group 1 (Tom and Liz) Playing Portal 2

During this session the intermediate level player Tom and the beginner level player Liz together played the first two chambers of *Portal 2* over two sessions. Even though Liz identified herself as a novice player in the before-session questionnaire (this might be due to the fact that the beginner level was not provided as a choice in the before-session questionnaire), her lack of experience with PS3 console games and her inability to adapt to the gameplay indicated that she was more at a beginner level. This research session was Liz's first experience with a PlayStation 3 (PS3) gaming system, and understandably she had a hard time maneuvering through the game space and getting used to the PS3 controllers at the beginning. Tom, on the other hand, was an experienced player, not only because of how many other PS3 games he played in the past but also because of his game play experience with the first game of the Portal series. Tom’s familiarity with the Portal game series gave him an advantage in understanding the main premise of the game. However, at certain times his previous knowledge of the game became a small hindrance, since he was trying to fit a new encounter into an existing cognitive structure. For example, when they faced the killer robots for the first time in this game, he mentioned that they probably could not kill the robots, because the first game did not allow the players to kill the robots. Therefore, their resolution to that puzzle was delayed until he realized that this game had slightly different rules, and killing the robots was one of the main tasks that lead to the solution.

Tom and Liz played the tutorial, first and second chambers of this game over two research sessions. During session one, the team was able to complete the tutorial and the first chamber in approximately two hours. During the second session the team completed most of the testing courses in chamber two in approximately 1.5 hours. The session two was ended abruptly before they could complete the last testing course due to the fire alarm that went off in the facility where the game play session was taking place.

Tutorial chamber.

The tutorial session provided the players with opportunities to learn how to play the game and how to utilize the game entities to work as a team. During this section Liz struggled with the gameplay, but Tom was able to complete the game tasks quickly and help Liz afterwards.

Collaboration and joint problem space.

Level of collaboration was minimal at the tutorial session. As Liz struggled with the game play, Tom explained the game basics to her during the tutorial session. The discrepancy between the levels of experience of the teammates combined with the easy tasks given in the tutorial rooms resulted with a heavy one-sided problem solving activity, rather than collaboration. Tom mostly solved the problems himself and then after completing his part of the task, he patiently helped out Liz so that she could complete her part and they could advance to the next room. The difference in the experience levels also influenced the group dynamics in an unbalanced way. While on a few occasions Liz felt comfortable enough to suggest and idea, Tom would focus on what he thought was the solution to the problem. Liz's timid way of proposing her ideas did not encourage Tom to test them until he would be out of solutions. For an instance, when they were struggling to find a way to get the cube to the floor switch in room six, Liz suggested that he should go on the moving platform. Tom indicated his disapproval of her idea and focused on finding other ways to solve this obstacle. However, when in the end he could not find a solution, he then tested out Liz's suggestion and stepped on to the moving platform, which resulted with the death of his character. Similar situations across the tutorial session caused this initial unbalanced group dynamics and it continued until Liz became more comfortable with the game mechanics.

These unbalanced group dynamics is also portrayed in the distribution and the frequency of functional roles that the each player assumed. During tutorial level, Tom and Liz assumed a role in the activity of problem solving a total of 197 times. Of these 197 times, Tom proposed 11 strategies and Liz proposed 7 strategies. For other times, they either executed moves independently from each other or one executed a move after receiving an explanation from the other one. Although Liz executed more independent moves, total of 65, then Tom, total of 55, majority of Liz's independent moves were incorrect. Several times, Liz asked for Tom's help during this level, and Tom explained her what she needed to do for 27 times. While Tom did not implement any of Liz's ideas, mostly executed his ideas without asking Liz, Liz implemented Tom's proposed ideas for 11 times. More detailed information about the distribution of the functional roles they assumed during this level is provided in Table 5. Overall, during the tutorial level this group executed more moves independently (61%) than together (39%) by trying to discuss a strategy and implementing it.

Table 5

Functional Roles Count – OCAF models

Functional Role	Tom		Liz		Total	
	N	%	N	%	N	%
Execution	55	45.83	65	54.17	120	60.91
Implementation	0	0.00	11	100.00	11	5.58
Proposal	11	61.11	7	38.89	18	9.14
Contestation	0	0.00	1	100.00	1	0.51
Rejection	1	100.00	0	0.00	1	0.51
Acceptance	4	80.00	1	20.00	5	2.54
Modification	3	75.00	1	25.00	4	2.03
Reasoning	0	0.00	0	0.00	0	0.00
Testing	10	100.00	0	0.00	10	5.08
Explanation	27	100.00	0	0.00	27	13.71
Total	111	56.35	86	43.65	197	100.00

Influence of Game Design Elements.

Challenge.

Although tutorial level had seven rooms, the participants' view on how challenging this section was only collected at the end of the level instead of at the end of each room. While Tom's reported challenge rating was 6 on a scale of 20 for the tutorial level, Liz's rating was 16. Both teammates reported that they enjoyed playing this level and rated the adequacy of the challenge as moderate (by Tom) and as fair (by Liz). The large difference between how they perceived the challenge level of this section of the game might have played an important role on why Tom was more contributory then Liz. Although Liz found this level very challenging, she also reported that the high level of challenge was fairly adequate for her. Therefore, at her case the high level of challenge that she experienced likely influenced her contribution to the collaboration but did not affect her enjoyment of the game or engagement with the game play.

Sensory stimuli elements.

The tutorial level provided a wider range of sensory stimuli elements, as one of the aims of this level was to scaffold the players' abilities before they can take on more complex challenges. Tutorial level of *Portal 2* utilized verbal and visual sensory stimuli elements as feedfront mechanisms that guided and informed players, and as feedback mechanisms that informed players about the consequences of their actions. The occurrence of the sensory stimuli elements and player's immediate reaction to these, as well as the immediate action it triggered are listed in the Table 6.

Table 6

Group 1 Sensory Stimuli Events During Tutorial Chamber

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
Auditory	Directive	Glados telling them to use their ping tool.	B-E	Liz pings the walls. Tom: "Aahh".
		Glados telling them to portal to a ledge.	A-E	Tom: "By portaling to a ledge?" Looks around and sees the ledge "that ledge".
	Corrective	Glados telling them that they can put portals on white surfaces.	A-P B-P A-A	Tom: "Oh, so we have to move some" Liz: "So not on that type of surface, how about this wall?" Looking at a white colored wall.
	Informative	Glados indicates that they were supposed to catch a cube.	A-P	Tom: "Oh it drops into the acid, so if you press it again this time I can catch it"
Visual	Directive	R1+L1 shows on screen	A-E B-E	Liz: "What is R1?" Tom: "Ok, so R1 to create portal, ah"
		R2 -Zoom shows on screen	A-E	Liz presses R2 by mistake, and R2-Zoom text appears on her screen. After seeing this Tom presses R2 as well "Ah, R2 is the zoom. That's nice."
		"Activate" appears on screen	A-E	Tom: "I don't know how we are going to do this, but there is a little thingy with activate on it, so if I activate it..."
		"Pick Up" appears on screen	A-X	Tom: "Oh again with square you can pick up that box that just got dropped"
		X mark on doors	B-E	Liz goes up to the exit door that has a X on it and says: "So do I start where the X's are?"
	Informative	Shape of the box and floor switch	A-E	Tom: "Looks like it is going to fit just right"
		Picture on the floor	A-P	Tom: "Now this I don't know what we are going to have to do" Looks down at the pictures on the floor when he first enters the room. Later on when they are trying to identify solutions, they look back at this picture again. Tom: "Don't drink the water, and if you swim you die. I guess that's what that means"

Notes. [a]A: Tom B:Liz / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

As mentioned before, during the tutorial the level collaboration was at minimal, hence the influence of sensory stimuli elements on collaboration was not showcased extensively. The results in Table 6 indicate that Tom and Liz reacted individually mostly to directive feedfront elements provided by the game through visuals. These visual sensory items include color change in buttons, cubes, and dotted lines; appearance of text and shapes on screen such as “R1-Create Portal” or “□ - Activate”; displays of figures and pictures on the floor and walls, etc. More generically the tutorial level and the rest of the game provided omnibus visual cues such as white color walls for the portable surfaces, faded blue color for the force shield, bright red color for the buttons, and solid or transparent look of portals. When these omnibus sensory elements combined with verbal sensory elements, the players were able to figure out what they had to do to solve the puzzles. However, the combination of sensory stimuli elements provided during this level of the game did not strengthen or weaken this team’s collaboration effort, except at once instance. During a time when they were struggling to figure out how they were supposed to get a cube in room 6, Liz pressed a button and released a cube that fell into acid water and disappeared. Upon that Glados immediately said: “Nice catch Orange!” in a sarcastic manner. When Tom heard this verbal informative feedback, he realized that they need to work together to get a cube and said: “Oh it drops it (cube) into the acid, so if you press again this time I can catch it.” This could be referred as the only instance of sensory stimuli leading to a collaborative act between those two during the tutorial.

Clarity of goals and rules.

Both team members rated the clarity of the goals and rules in a similar fashion. While Tom’s rating was 23 on a scale of 30, Liz reported 20 as the score for her perception of the clarity of the goals and rules of the tutorial level. Since *Portal 2* provides repetitive goals and objectives and the rules are consistent throughout the game, it was easier for the participants to identify them. However, most of the operational rules of the game were found out through trial-and-error.

Chamber I (Team Building).

In the last two-thirds of their first session, group one tackled the challenges brought forward in the testing courses of chamber one. The group members verbalized that they were happy that they were in the same test room in the game world instead of the glass-separated rooms. They also mentioned that they were happy that they were sitting next to each other in the same room and not playing this game online.

Tom: "I am really glad we are in the same room. I know one of the things at the beginning said you can play online, but I can't imagine." Liz: "I know trying to communicate with someone that you are not next to."

Since Liz got some gameplay practice under her belt, her ability to move in the game world of this chamber was slightly improved and it seemed that she was feeling more comfortable with the game controls. However, she was still passive at proposing ideas and standing behind of her ideas after proposing them. Although their first true collaborative problem solving act took place in the testing course two of the chamber one, there were still some issues with the balance of the group dynamics. At some point at the end of a testing course, Tom just took over and completed the testing course by himself, but then he apologized to her saying: *"I am sorry I should have been talking to you about what I was doing"*. They spent an average of 8 minutes 54 seconds on each testing course of this chamber with course three taking the longest time (18 min 58 sec) and course one taking the shortest time (4 min 37 sec).

Collaboration.

The group showed increased level of collaboration during chamber one. Throughout six testing courses they played, their level collaboration improved from the first testing course to the last one. During the first testing course, Tom was still dominating the problem solving activity and taking the lead at identifying what they needed to do. While in the first testing course Tom proposed all of the ideas for the solution and Liz just followed his directions, as the game progressed Liz started to contribute to the problem solving activity. First signs of collaboration started to surface during this level of the game. In testing course two, for the first time, they came up with a strategy somewhat together and implemented it together. While Liz was avoiding executing her own ideas and just timidly stating them for an open discussion, Tom was more confident in what he was doing and executing most of his ideas himself or with the help of Liz to test them. However, Liz’s timid behavior started to change towards the end of this session of gameplay. The distribution of their functional roles presented in Table 7 reveals the changing balance in their group dynamics. Although not optimally equal yet, their apt for collaboration shows some indication that in the next sessions they will showcase a more balanced distribution of functional roles.

As can be seen in Table 7, Tom and Liz partook in joint decision-making activities 69% of the times (N=236). Their joint decision making activities consisted of proposing ideas (N=58), implementing ideas (N=133), modifying a proposed idea (N=8), contesting a proposed idea (N=1), rejecting a proposed idea (N=11), accepting a proposed idea (N=11), stating reasons behind an idea (N=2) and testing an idea (N=12). Of these 58 times of proposing ideas, Tom proposed 46 strategies and Liz proposed 12 strategies. For other times, they either executed moves independently from each other or one executed a move after receiving explanation from the other one. Tom still executed more independent moves, total of 66, then Liz, total of 24. The number of times that Liz asked for Tom's help during this level was reduced to 14.

Table 7

Frequency of Functional Roles Assumed During Portal 2 Chamber 1

		Testing Course 1		Testing Course 2		Testing Course 3		Testing Course 4		Testing Course 5		Testing Course 6		Tom Total	Liz Total	Total
		Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz			
Execution	N	10	6	4		10	2	7	12	8	2	27	2	66	24	90
	%	62.5	37.5	100		83.33	16.67	36.84	63.16	80	20	93.1	6.9	73.33	26.67	26.47
Proposal	N	16	0	7	4	8	4	8	1	5	1	2	2	46	12	58
	%	100		63.64	36.36	66.67	33.33	88.89	11.11	83.33	16.67	50	50	79.31	20.69	17.06
Implementation	N	7	14	21	15	15	11	5	8	5	8	17	7	70	63	133
	%	33.33	66.67	58.33	41.67	57.69	42.31	38.46	61.54	38.46	61.54	70.83	29.17	52.63	47.37	39.12
Modification	N	0	0	1	0	4	0	0	0	2	0	1	0	8	0	8
	%	0	0	100	0	100	0	0	0	100	0	100	0	100	0	2.35
Contestation	N	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1
	%	0	0	0	0	100	0	0	0	0	0	0	0	100	0	0.29
Rejection	N	0	0	0	0	8	0	1	1	0	1	0	0	9	2	11
	%	0	0	0	0	100	0	50	50	0	100	0	0	81.82	18.18	3.24
Acceptance	N	0	0	1	0	0	3	0	1	1	4	1	0	3	8	11
	%	0	0	100	0	0	100	0	100	20	80	100	0	27.27	72.73	3.24
Reasoning	N	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
	%	0	0	100	0	0	0	0	0	0	0	0	0	100	0	0.59
Testing	N	0	0	2	0	5	0	0	0	1	0	4	0	12	0	12
	%	0	0	100	0	100	0	0	0	100	0	100	0	100	0	3.53
Explanation	N	0	0	2	0	8	0	2	0	1	0	1	0	14	0	14
	%	0	0	100	0	100	0	100	0	100	0	100	0	100	0	4.12
Total	N	33	20	40	19	59	20	23	23	23	16	53	11	231	109	340
	%	62.26	37.74	67.8	32.2	74.68	25.32	50	50	58.97	41.03	82.81	17.19	67.94	32.06	100

Joint problem space.

Tom and Liz's shared understanding of the problem and the goals related to the problem that they were facing were examined through their in-game conversations. During this chamber, Tom and Liz were always able to identify the end goal of the each testing course, as the repetition of the game made that obvious.

Tom: "That's the door I bet we have to go through." … Tom: "There are the doors now."

Every time they entered a new room they looked around and identified the final door that they should be reaching to complete the levels. These end goals were mainly identified by Tom individually but he always made sure to share his understanding of the game goals with his partner.

During the construction of the shared understanding of the problem, Tom and Liz would mostly examine their environment and identify their initial state and their end goals quickly. They were also able to dissect the problem space into smaller pieces through identifying the middle stages and solve each piece to together to reach the end goal. However, the identification of the middle states that they have to go through to solve the problem mostly would come to them after a few trial-and-error and negotiations. The example conversation below showcases how Tom and Liz develop a joint problem space:

Tom: "There is an X on the floor there and a dot on here. Oh, a moon, a wedge (symbols) and all four symbols up there. But I have no idea what all these mean. Liz: "I see a lot of portal places though." Tom: Yes and there are tower buttons." Tom: "I bet if we get all four of these pressed at the same time, that door (exit *door) will open for us." They explore the room a little more. Tom: "I bet if we step on this (floor button) we get a box." They both step on the floor button several times and nothing happen. They explore the room more in detail. Liz: "Maybe we have to do all four (press all four buttons) then the cube will come?" Tom: "I bet that is right. Because if we put a cube on that (floor switch), then the door will open."*

This conversation showcases how Tom and Liz quickly identify the initial states of the problem by talking about their game environment. As this conversation suggest, the team easily identifies the end goal, the initial states, and possible actions. However, the middle states and associations between possible actions and states are discovered through trial-and-error and negotiations between the teammates.

Influence of Game Design Elements on Collaborative Problem Solving.

Challenge.

The participants' perception on challenge level of each testing course was collected. Table 8 presents Tom and Liz's ratings of the difficulty of each testing course as well as the frequency of their functional roles during this collaborative effort. As seen in the Table 8, this team resorted to a more collaborative approach during testing course two to five. Of these four testing courses, during three of them (Testing course 2 gap=2, testing course 3 gap=5, testing course 5 gap=2) the gaps between the perceived difficulty levels between two teammates were at a low level. The gaps are calculated by subtracting the each teammate's challenge rating (presented in Table 8) from each other. The gaps in challenge ratings of teammates will be arbitrarily categorized under four levels for the ease of comparison: low gap (5 or below), medium gap (between 6 and 10), high gap (between 11 and 15), and very high gap (between 16 and 20).

Table 8

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Testing Course 1	Tom	2	10	16	7	0	0	0	0	0	0	0
	Liz	11	6	0	14	0	0	0	0	0	0	0
Testing Course 2	Tom	3	4	7	21	1	0	0	1	2	2	2
	Liz	1	0	4	15	0	0	0	0	0	0	0
Testing Course 3	Tom	5	10	8	15	4	1	8	0	0	5	8
	Liz	10	2	4	11	0	0	0	3	0	0	0
Testing Course 4	Tom	2	7	8	5	0	0	1	0	0	0	2
	Liz	9	12	1	8	0	0	1	1	0	0	0
Testing Course 5	Tom	5	8	5	5	2	0	0	1	0	1	1
	Liz	3	2	1	8	0	0	1	4	0	0	0
Testing Course 6	Tom	4	27	2	17	1	0	0	1	0	4	1
	Liz	11	2	2	7	0	0	0	0	0	0	0

If we look at the individual scorings of each teammate, we can see that except during testing course two and five Liz felt more challenged than Tom. During the less challenging levels she felt more comfortable about contributing to the problem solving activity and providing ideas for the solution. As they progress in the game, she became more accustomed to PS3 gameplay style and tried to execute more moves by herself during exploration of the levels. On the other hand, Tom reported that the challenge levels of these testing courses were relatively easier. He executed most of the moves by himself without discussing with his partner. Due to the exploratory nature of the game that does not punish the player for making mistakes, both players felt comfortable about killing their avatars during the game for the sake of trying to find an answer to the problem or applying their proposed plan of solution. Tom took advantage of this privilege the most and executed moves and tested his ideas.

During testing course three the team displayed a larger variety of functional roles, which indicated a more wholesome collaboration with diversified roles. They both proposed ideas, Tom more so than Liz, and implemented their plans into action together. However, Tom again was leading the collaboration, as he rejected and modified some of Liz's suggestions. During this level the difference between the teammates perception of challenge levels were at a medium level. However, individual reported challenge levels for each teammate were fairly high.

During testing course two, the teammates did not execute moves by themselves a lot, and agreed on a plan quickly to solve the puzzle. As can be seen from the table, this testing course was deemed as one of the easiest by two of the team members. Since during this testing course both members of the team also proposed ideas and implemented them together, it can be concluded that the level of collaboration was more balanced than the other testing courses.

As mentioned earlier, Tom and Liz overcame all of the challenges given to them and solved each and every problem tasks provided in this chamber. However, the number of strategies they employed to solve the problems and the duration of the problem solving activity varied across the testing courses. While in some testing courses, they felt more challenged and exhausted numerous ideas before they could accomplish the right solution for the given problem task, in others they were quickly able to identify what needs to be done to be able to reach the end state.

Testing course three was amongst one of the most challenging testing courses for them, as can be seen from the high challenge scores given by the two teammates. This was also stated at the end of the testing course by Tom.

Tom: "This is way harder than the other one (Portal 1) was, but this is cool how much you have to re-direct things."

In this example Tom was reflecting back on his experience with Portal 1 and comparing the level of challenge between the two games.

During this challenging testing course the team generated various ideas to overcome the problem. They were able to discern their initial state (their location upon entering a testing course) and the end goal (reach the exit door). However, it was not easy for them to figure out what they needed to do to get from initial state to the end goal. Eventually, after experimenting with their environment and testing various ideas, they were able to identify the two major middle steps: Destroy the robots to clear the path, and redirect laser beam towards the two receptors using portals. Ultimately they implemented two overarching strategies during in this testing course. They were aware that they were supposed to pass through the robots, and if they got close to the robots they would be shot. The first strategy they employed was the use of Portals to bypass the robots; however, this did not work in their favor. Later on they realized that they could destroy the robots via re-directing the laser beam onto them. After destroying the robots, they tried re-directing the laser beam straight on to one of the receptors, hoping that it would do something. After realizing the insignificant result of this action, they figured that they needed to pass the laser through both receptors at the same time in order to activate something that will allow them to get to the exit door. This example shows that when the level of challenge is higher this team tested more ideas and failed at some points, but since the game does not punish the failure they tried other ideas until they found the right combination. They also took a longer time to identify all the right states in the middle and the possible actions associated with those states.

Overall the increased level of challenge only made the process of problem solving more time consuming, but not impossible. Also, the difference between the level of challenge reported by Tom and Liz reflected on their role in verbally identifying the states and operators. Tom was quicker in expressing what needs to done by verbalizing the initial states and end goals as well as coming up with complete strategies. Conversely, Liz only contributed to the identification of some of the possible actions.

Sensory stimuli elements.

Although the testing courses in Chamber I lacked the verbal feedback given through audial sensory stimuli like it was during the tutorial level, the visual feedback elements were provided extensively. The team members reacted to most of the visual stimuli elements provided during these testing courses. For example, when they saw a large sign on the wall they examined it before they proceed to explore the each testing course:

> *Tom walks up to the wall sign and examines it. Tom: "So we have that same thing. Oh, I think this telling us that we have water that we can't go in and cubes that we will have to worry about."… Both Tom and Liz come close to the wall sign and inspect it. Tom: "I think they are going to shoot at us." Liz: "I see cube.” …Tom: "Something tells me that is only half of it though" Liz: "Yes, because we still have to figure out that cube."*

These conversations above are examples of verbal reactions that Tom and Liz gave when they encountered informative visual sensory stimuli elements that served as a feedfront mechanism. Although these wall signs did not generally trigger an immediate action (or a functional role) in the game environment, they instigated conversations in which the players shared their understanding of the problem. Through conversing about these wall signs the team members also identified the problem states and possible actions that would allow them to solve the problems.

Changing color of dotted lines was utilized in this game to indicate which game objects were associated. These directive sensory stimuli elements used as feedback mechanism intrigued Tom and Liz in almost every occasion. When the color of dotted lines changed they expressed their understanding of how this sensory change provided them with clues:

> *Tom: "Now I am going to come in here to see where that dotted line goes." He walks in the other room and says:"Oohh, OK. So we can open that door from both sides."… Tom: "What is that thing up there? Doesn't it look like we need to put something in there? And then those blue dots will turn orange."*

In this conversation, Tom utilized the dotted lines to understand the states of the problem (door needs to be open from both sides). His understanding of the function of this sensory stimuli element allowed him to generate an idea (we need to put something in there) and propose this to his partner. Therefore, in this example this directive sensory stimuli element supported a collaborative functional role (proposing an idea). Their reaction to the sensory stimuli elements were mostly followed up with actual action taken in the game. The list of the sensory elements and the corresponding action are provided in the Table 9.

Table 9
Sensory Stimuli Events in Chamber 1

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
Visual	Directive	Dotted Lines	A-E	Tom: "Now I am going to come in here to see where that dotted line goes." He walks in the other room and says: "Oh, OK. So we can open that door from both sides."
		Symbols and Color Change	A-P A-S A-I	Tom: "Oh Ok I bet we have to get all four buttons pressed relatively quickly. Because you see like when I press the X button here it turns orange. But then it fades away"
		"X-Jump" appears on screen	B-E	Liz: "I have to jump?" Tom: "Yes otherwise you will hit the laser."
		Dotted lines and distinct shape of objects	A-E	Tom: "So we have one, two, three things to hit with the laser." He picks up the cube.
		Insert disc sign	A-E	Tom: "Is there a disk in here?" He starts looking around.
		"Hold for countdown" appears on screen	A-E A-P A-I B-I	Tom tries to start countdown, but he is not sure what he is doing. After figuring it out. Tom: "Oh I see, I just learned something else. The top directional arrow is countdown, so we can pull it together, like exactly together.
	Informative	Picture of a sphere on the floor switch	A-E B-E A-P B-I A-I	They both try to activate the switch and failed to do anything. Tom: "Umm it has a dot on it, so maybe if you go stand and I press the dot button it will do something."
		Distinct shape and material of the glass cube	A-M A-I	Tom: "I wonder if we put the box under the laser if things will happen. You see how it is like a weird box. That's kind off clear sort of."
		Moving platform	A-E	Liz: "What is the..." Tom: "Yeah what is the purpose of this?" Liz: "Yeah." Tom: "It sorts of reveals them (robots)."
		Picture on top of a button	A-E	Tom: "If we hit this..." Tom presses the button. Liz: "If we hit this a cube comes out."
		Distinct color	A-E	Tom tries to activate the shiny green dot on the vault.
		1 and 2 appears on top of each switch	A-P	Tom: "Of there is one and there is two. I bet we both have to do it."
	Decorative	Moving panels on wall	A-P B-I	Liz sees moving boxes on the wall. Liz: "I just saw those boxes move" Tom:" If you go stand on the button maybe, then did the boxes move or anything?" Liz: "No, it is just cameras I think."
		Cameras with red light	A-P B-A A-I	While trying to figure out where to point the laser tom sees the camera. Tom: "What about like... Is that a thing?" Liz: "Maybe, let's try it."
Auditory	Informative	Sound of a door opening	A-I B-I	Liz: "Did it do anything?" Tom: "(Looking towards the door) It might have actually. Let's try again."

Notes. [a]A: Tom B:Liz / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

Although some sensory elements did not result with an immediate corresponding action, it led to conversations that allowed them to progress towards solving the problem later in the game. For example, when Tom and Liz encountered a set of moving panels (an informative sensory stimuli) in testing course three, at first they were not sure what this was supposed to be useful for, but this sensory stimuli element still grabbed their attention and allowed them to focus on the game objects that are essential for the problem solution:

> *Liz: "What is the..." Tom: "Yeah what is the purpose of this?" Liz: "Yeah." Tom: "It sorts of reveals them (robots)."*

During this chamber the effective use of visual feedback elements combined with their increasing comfort level with the game resulted with demonstration of more functional roles and yielded more substantial collaboration. Mainly with the help of directive and informative feedfront elements, Tom and Liz were encouraged to work together. They proposed, tested, and implemented various ideas right after they were provided with a sensory element in the game. Although it is possible that sensory elements essentially play a more important role in helping them solve the puzzles individually, they also help shape the conversation and the actions that they showcase during this game. For example, in room 2 while they were trying to figure out what to do with the cube, Liz suggests that they should move it to somewhere else. When Tom realizes that the box has glass/clear looking sides, he modifies her initial proposal and suggests that they should move the cube under the laser:

> *Tom: "I wonder if we put the box under the laser if things will happen. You see how it is like a weird box. That's kind off clear sort of."*

In another case, after both of them failed at trying to activate a floor switch they changed their strategy and Tom proposed a different idea:

Tom:"Ummm it has a dot on it, so maybe if you go stand and I press the dot button it will do something."

Then, with the help of another sensory stimuli element they realized that they need to come up with a different plan to be able to solve this problem:

Tom:"Ohh Ok I bet we have to get all four buttons pressed relatively quickly. Because you see like when I press the X button here it turns orange. But then it fades away"

This chamber also provided sensory elements that did not serve any feedfront or feedback purpose, and made them generate wrong solutions, but stimulated some collaborative effort between the players. For instance, while trying to figure out where to point the laser in room 2, Tom sees a camera that has a red light on it.

Tom: "What about like…Is that a thing?" Liz: "Maybe, let's try it." Tom: "OK, maybe you should go over there to watch where I am pointing the laser."

Overall there were mainly visual directive and informative feedfront sensory elements in this chamber and these elements –along with other reasons-helped increase the frequency and the variety of functional roles demonstrated by this team. As an immediate outcome of being exposed to sensory stimuli, the team took part in proposing solutions, implementing ideas, and executing individual moves. Although rare, reasoning, modifying a proposal and testing an idea was among other functional roles demonstrated as a consequence of sensory stimuli during this chamber.

Tom and Liz took various sensory stimuli elements into consideration while they were trying to build a shared understanding of the problem. The visual feedfront elements, the most commonly encountered sensory element during this chamber, played an important role during the collaborative problem solving for this team. They took advantage of wall displays to identify what they might be facing during the game (middle states). For example in testing course two, Tom walked up to the wall sign and after examining it he said: *"So we have that same thing. Oh I think this telling us that we have water that we can't go in and cubes that we will have to worry about."* In another testing course, both Tom and Liz inspected the wall sign and had a small conversation about it: *Tom: "I think they are going to shoot at us." Liz: "I see cube."*

Also, they were able to anticipate whether they will be completing the testing course after going through a door based on the cues provided on the wall display:

> *Tom: "Something tells me that is only half of it though" Liz: "Yes, because we still have to figure out that cube (that was shown on the wall display)."*

The other types of visual sensory stimuli items that help them identify their state and all the steps that need to be taken to complete the puzzle included dotted colors that provided information regarding which switch was opening which door, figures and text appearing on the screen that provided very straight directions to what they should be doing (e.g. X -Jump). [*Liz: "I have to jump?" Tom: "Yes otherwise you will hit the laser."*], and the distinct shapes and colors of the games items such as portable walls, buttons, cubes, and laser beams.

Some of these visual feedback elements did not immediately help them solve the problem or perplexed them at the first time of encounter. However, due to the gaps those sensory elements generated in their understanding of the problem, they were able to focus on those issues and identify a solution to the problems.

Tom: "There is an X on the floor there" Liz: "There is a symbol." Tom: "There is a dot there." He looks up and sees the other symbols. Tom: "Oh OK we got a moon and a wedge and all four symbols up there. I have no idea what that means."

Liz: "What is the..." Tom: "Yeah what is the purpose of this (moving panels)?" Liz: "Yeah." Tom: "It sorts of reveals them (turret robots)."

Here we see the examples of how both Tom and Liz’s curiosities were awoken by these sensory stimuli elements that they encountered. In return, they realized that these sensory stimuli elements were essential to the problem that they were facing. Consequently, they collaborated to identify the purpose of these sensory stimuli elements and generate a solution.

On the other hand, during this chamber it wasn’t clearly observed that the team reacted to the auditory sensory clues provided to them. The examples of these auditory sensory elements include the ticking noises that imply the limited amount of time available for action after pressing a button and door opening or button pressing noise. Although in testing course six, after pulling down the switches together, Tom was suspicious that the door was opened even though he was not looking at the door at the moment. This could have been an indicator that they were actually using some of the auditory cues during their problem solving activity.

Liz: "Did it do anything?" Tom: "(Turns towards the door) It might have actually. Let's try again."

Overall, the team successfully identified all of the states, possible actions, and the association between the states and actions during the each testing course with the help of various sensory cues provided by the game.

Clarity of the goals and rules.

Tom and Liz's perceptions on the clarity and easiness of understanding the level goals and the rules were measured by 6 questions with a scale of 1-Not Clear/Easy at All to 5-Very Clear/Easy. The aggregated scores of Tom and Liz on this scale are provided in Table 10.

Table 10

Reported Clarity of Goals and Rules

	Clarity of the Goals and Rules	
	Tom	Liz
Testing Course 1	25	22
Testing Course 2	29	30
Testing Course 3	26	25
Testing Course 4	24	26
Testing Course 5	26	30
Testing Course 6	20	27

During this chamber Tom and Liz did not have any trouble in identifying the end goal of the game, as well as the mid-point goals of the game. The high scores provided above reflect the notion that they felt that it was easy for them to be able to figure out what they needed to do in order to solve the puzzles. Here are some of the excerpts from their conversation that showcases their ability to develop a joint problem space:

Tom: "That's the ultimate door." (End goal identified.)

Tom: "We have a portal place here." Liz: "And there is one right there too." (Part of identification of the initial state)

Tom: "We have portal walls and this door that we can only open from the other side." (Part of identification of the initial state)

Tom: "I think one of us has to be in the first chamber. There are also portal walls there." (Middle state identified)

Tom: "If you go through that portal I will open the door for you, and we will figure out how to get me there." (Actions identified.)

Liz: "I probably have to come back and portal you here." (Actions identified.)

Liz: "Maybe we have to do all four (press all four buttons) then the cube will come?"(Actions identified & middle state identified) Tom: "I bet that is right. Because if we put a cube on that (floor switch), then the door will open.(Actions identified & end goal identified)"

Their conversations and actions during the game indicated that they were able to construct a shared understanding of the problem with little or no effort. Above we see the instances of when Tom and Liz were able to understand the goals of the game and share their understanding with each other.

Although this game provided clear and consistent procedural rules and repeating end goals across the testing courses, the slight variations in the quantity and the nature of the procedural rules made the testing courses differ from each other. Tom and Liz were aware that they will have to open the exit door to proceed, but what they needed to do to open the exit door was different at each testing course. For example in several previous testing courses, they had to step on red circular objects located on the ground to open the doors, but in one of the testing courses, the orangish colored circular object located in the ground was used as a switch that required them to drop a ball in it. In this case, the previously built understanding of that procedural rule caused them to misidentify the states of the problem. In testing course two, Tom and Liz tried to step on and activate a circular object located on the ground, thinking that it would open the door for them. After trying for a while, they realized that this procedural rule does not apply to that circular object located in the ground. Tom and Liz clearly identified some of the more consistent procedural rules that were supported by the visual sensory elements and the result of acting upon them:

Tom: "If we hit this.." Liz: "If we hit this a cube comes out."

The teammates identified that pressing buttons to release cubes was a consistent procedural element. Liz verbalized the anticipated result of hitting this element in this example.

Most of the operational rules were clearly presented to the players through the wall displays (Figure 3). Tom and Liz thoroughly inspected each wall display at the beginning of each testing course to clarify what they can or cannot do or what they should expect from a testing course. However, Tom and Liz also had to learn about some of the operational rules of this game along the way. For example, there were not any clearly represented operational rules regarding shooting portals through glass or force fields, they learned that they cannot shoot portals through glass or force fields through trial-and-error at the earlier levels of the game. Later on, this gained understanding played a role in how they understood the shared problem space and came up with solutions:

Tom: "There is portal wall here. So I bet since I can't launch one (portal) form here (behind the glass) one of us has to have a portal from that room to this wall here."

In this example Tom expresses his understanding of the operational rule of not being able to shoot portals through the glass. His understanding of this rule allowed him to identify the problem state (two portals in different locations) that they need to proceed to and therefore propose a partial solution (that one of them who is not behind the glass has to provide a portal on each location).

Chamber II (Mass and Velocity).

In the second research session, Tom and Liz continued to play *Portal 2*, and they completed the six of the eight testing courses provided in chamber II in under an hour of gameplay. They spent an average of 12 minutes 21 seconds to complete each the six testing courses of this chamber with testing course five taking the longest time (24 min 46 sec) and testing course two taking the shortest time (5 min 54 sec). The team displayed increased levels of preliminary discussions before they took any actions in the game during this session. Also, they were quickly able to understand the steps need to be taken in order to reach the end goal (identifying the states), however they mostly took longer time to figure out how to get to those identified states (actions). The increased gameplay difficulty combined with increased puzzle difficulty of the testing courses provided in chamber two also caused them to take longer time to complete this level. The gameplay mechanics were significantly increased in complexity, which reflected in Liz's gameplay ability. For example, instead of simply pressing buttons and going through portals, in this chamber they had to use increased velocity to shoot from portals to reach places, or use the velocity to fall from high places and simultaneously press buttons while in the air. These game actions required them to be more precise and quick in placing portals or moving around the game world, which was mainly troublesome for Liz.

Collaboration.

Although during this session it was observed that Liz was more confident and her contribution was becoming more assertive, overall the group dynamics were still unbalanced. Tom was still the leading idea/solution provider, while Liz mostly accepted and implemented his ideas. However, it is important to note that when Tom struggled to come up with a solution, Liz stepped up and provided partial key solutions to the problems they faced.

During the joint decision making process, the collaborative roles that the team assumed composed 76% of their actions (Table 11). Their joint decision making activities consisted of proposing ideas (N=29), implementing ideas (N=182), modifying a proposed idea (N=9), contesting a proposed idea (N=2), rejecting a proposed idea (N=1), accepting a proposed idea (N=4), stating reasons behind an idea (N=3) and testing an idea (N=8). The decreased number of proposing action and the increased number of implementing action indicated that the team is coming up with a solution quicker, but it is taking longer for them to execute the plan due to the increased difficulty of the gameplay.

Table 11

Frequency of Functional Roles Assumed During Portal 2 Chamber II

		Testing Course 1		Testing Course 2		Testing Course 3		Testing Course 4		Testing Course 5		Testing Course 6		Tom Total	Liz Total	Total
		Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz			
Execution	N	9	2	2	1	3	1	4	2	13	5	16	7	47	18	65
	%	81.82	18.18	66.67	33.33	75	25	66.67	33.33	72.22	27.78	69.57	30.43	72.31	27.69	20.7
Proposal	N	7	0	1	1	5	1	6	0	4	2	1	1	24	5	29
	%	100	0	50	50	83.33	16.67	100	0	66.67	33.33	50	50	82.76	17.24	9.24
Implementation	N	18	10	11	10	7	10	36	23	14	20	10	13	96	86	182
	%	64.29	35.71	52.38	47.62	41.18	58.82	61.02	38.98	41.18	58.82	43.48	56.52	52.75	47.25	57.96
Modification	N	0	0	1	0	0	0	3	1	3	0	1	0	8	1	9
	%			100	0			75	25	100	0	100	0	88.89	11.11	2.87
Contestation	N	0	0	0	0	0	0	0	1	1	0	0	0	1	1	2
	%							0	100	100	0			50	50	0.64
Rejection	N	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
	%							0	100					0	100	0.32
Acceptance	N	0	1	0	0	0	0	0	2	1	0	0	0	1	3	4
	%	0	100					0	100	100	0			25	75	1.27
Reasoning	N	0	0	0	0	0	0	1	0	2	0	0	0	3	0	3
	%							100	0	100	0			100	0	0.96
Testing	N	0	0	0	1	0	0	3	0	4	0	0	0	7	1	8
	%			0	100			100	0	100	0			87.5	12.5	2.55
Explanation	N	1	0	2	0	1	0	2	0	1	0	4	0	11	0	11
	%	100	0	100	0	100	0	100	0	100	0	100	0	100	0	3.5
Total	N	35	13	17	13	16	12	55	30	43	27	32	21	198	116	314
	%	72.92	27.08	56.67	43.33	57.14	42.86	64.71	35.29	61.43	38.57	60.38	39.62	63.06	36.94	100

Joint problem space.

During chamber two, the players were introduced to new game environment elements such as springboards, and flinging action. Although these new game environment elements did not influence Tom and Liz's construction of problem space, they did increase the level of gameplay difficulty. In chamber two, much like in chamber one, Tom and Liz took a similar approach to exploring the area and constructing their understanding of the problem together. The first thing they did in almost every testing room was to identify their initial state and their end goal.

Liz: "Where do we have to end up? Tom: "Over there I think."

Tom: "So that's where we have to put the cube (Looking at a floor switch)."

Liz: "There is the target." Tom: "And there is the angled one (portalable surface)." Liz: "And it will shoot us up there."

As we can see here, Liz verbalizes the need to determine the goal. They engage in a discussion to identify the goal and the problem states.

Although it was easy for them to identify the initial and end states, figuring out what mid-states they need to go through and the actions that will allow them to switch from one state to the other were not always clear. In these cases, they experimented with ideas when they did not have an immediate solution in mind. They also took advantage of the repetitive nature of the game to solve the problem without precisely assessing the mid-states or the operators.

Tom: "I think each one those trails of blue dots leads to a place where one of us has to stand. I just don't know how to get there. But we can kind of do the same thing as last time (referring to flinging action)."

Influence of game design elements on collaborative problem solving.

Challenge.

Throughout this session there was a large discrepancy between the teammates' perceived level of challenge (Changing from very high to medium gap), except in testing course two. Based on the ratings that each teammate provided (presented in Table 12), it can be observed that the testing course five was one of the hardest testing courses for both of them. Overall, Liz felt challenged – rating the testing courses between 6 and 20 - , and Tom felt relatively less challenged – rating the testing courses between 2 and 6 - compare to the previous testing courses.

Table 12

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Testing Course 1	Tom	2	9	7	18	0	0	0	0	0	0	1
	Liz	17	2	0	10	0	0	0	1	0	0	0
Testing Course 2	Tom	3	2	1	11	1	0	0	0	0	0	2
	Liz	6	1	1	10	0	0	0	0	0	1	0
Testing Course 3	Tom	2	3	5	7	0	0	0	0	0	0	1
	Liz	16	1	1	10	0	0	0	0	0	0	0
Testing Course 4	Tom	3	4	6	36	3	0	0	0	1	3	2
	Liz	20	2	0	23	1	1	1	2	0	0	0
Testing Course 5	Tom	5	13	4	14	3	1	0	1	2	4	1
	Liz	20	5	2	20	0	0	0	0	0	0	0
Testing Course 6	Tom	3	16	1	10	1	0	0	0	0	0	4
	Liz	11	7	1	13	0	0	0	0	0	0	0

The first testing course of this chamber provided them with a new style of puzzle where the players had to use the flinging maneuver. This challenge was easily overcome due to Tom's existing knowledge of the first Portal game. Flinging maneuver, as explained in earlier sections, requires players to gain speed and velocity through falling into a portal from a high location so that they can shoot across large gaps upon exiting a portal. To Liz, this was a completely new phenomenon and it took a while for her to grasp the flinging maneuver. Initially, she just implemented what Tom told her and they were able to complete this testing course. This also was reflected in the distributions of the collaborative roles that they assumed. While Tom proposed all of the ideas for the solutions, Liz was just following his directions.

As one of easiest testing courses and showcasing the least discrepancy between their perceived levels of difficulty, testing course two resulted with minimal number of and diversity in collaborative actions. Tom and Liz both contributed one idea each to the solution and they were quickly able to overcome this task. On the other hand, testing course five proved to be the hardest testing course for them. During this testing course both players contributed to the solution together, tested various ideas, and spent longer time discussing about their ideas. In fact it was observed for the first time that Tom himself could not come up with a solution, and Liz was able to propose a very critical idea that helped them complete the testing course.

Interestingly, the most amount of discrepancy was observed in testing course four (gap=17). Although during this testing course the team mostly spent their time trying to implement their ideas, they still displayed variety of functional roles. This level required them to be precise and quick in game action taking such as placing portals or pressing buttons. Due to this gameplay complexity, Liz felt she was challenged, whereas for Tom it was an easier testing course.

During this chamber it was observed that the testing course four and five contained the most challenging and time consuming puzzles for the team. Although during the testing course four they exhausted various ideas in order to finally achieve a solution, the difficulty of the problem was not the biggest issue. As it can be seen from the Table 12, while Tom thought this was not really a challenging puzzle as much as the testing course five was, for Liz both testing course five and testing course four were equally challenging. As mentioned in previous sections, during the testing course four gameplay required taking precise and quick actions and movements in the game environment. Therefore, Liz, who had very little previous experience with playing PS3 games, found this level difficult in regards to maneuvering her game character. At various occasions they had to switch roles because she felt that she was not capable of delivering the game action that they planned on doing. On top of the challenging game play, the team had hard time identifying the middle states and the possible actions that would get them from one state to the other. However, they were able to identify the initial state and the end goal of this puzzle very quickly.

On the other hand during testing course five the problem task was more complicated than the gameplay. Testing course five also included three divided up sections which resulted with a longer problem solving activity. Of the three parts of testing course five, the last part troubled the team the most. During this part of the game, Tom and Liz did not identify their states as much as they did in other testing courses and directly dived into taking actions in the game. As they got stuck in the process of problem solving, they resorted to exploring the area more and trying to re-identify the middle states and actions.

One of the important things this case suggested is that there are different ways a game can be challenging and this can affect the joint problem solving activity. A game can be challenging due to its gameplay mechanics, or it can be challenging because of a difficult puzzle. In this case, the team communicated less about the states and operators when they faced a difficult puzzle and they took an experimental approach by taking actions (getting to the middle states) without planning out the rest. However, difficult puzzles allowed the passive team member to contribute more and promoted collaboration among teammates. When facing a testing course with a difficult gameplay, they planned out their actions and they knew what they were after. However it took a long time to for them to figure out the correct actions and middle states. In addition to that, encountering a difficult gameplay slightly discouraged Liz and made her think that she was not capable of performing the required action.

Overall the increase in the perceived level of challenge was reflected in the amount of time the team consumed as well as the number of strategies they implemented during the process of problem solving. Also, the continued difference between the levels of challenge reported by Tom and Liz indicated that Tom was still more comfortable and more dominant in expressing his ideas and coming up with strategies, although Liz contributed to the identification of some of initial states, middle states and the actions.

Sensory stimuli elements.

In the second session, as the players got used to the ways the game provided clues for them, their observations of the sensory elements helped them more and more during the problem solving activity. Tom and Liz both were very observant of their game environment as soon as they entered the testing courses.

> *Liz: "There are lots of portal places." Tom: "And here is the cube dispenser." After looking at the circular shaped floor switch Tom says: "Oh it is going to be a round one (correcting his first suggestion of cube.)"…"Tom: "We got lots of water we can't go in and portal places."… Liz: "Oh that is where the cube is."*

More importantly even after becoming more accustomed to the gameplay, they still took their time to examine the wall displays that are provided at the beginning of each testing course. In fact, during testing course one it can be speculated that the wall display that Tom observed helped him come up with his proposed idea. After focusing on the flinging action picture at the wall display Tom says: *"And this might be that we need to jump from one portal to another."* However, he also mentioned his previous gaming experience with the first game of the series. This could have influenced his proposal. Tom: *"In the first Portal game to do that [referring to shooting across a portal to reach across a large gap] we had to jump through portals a few times."* Therefore, in this case it could be a combination of sensory stimuli item and his previous knowledge that allowed him to assume this functional role (Proposing an idea).

During this chamber the team also initiated longer discussions before they took any actions, and they observed their surroundings. Most of the times, Tom was more successful at identifying the visual sensory elements provided by the game and proposing strategies based on that. In testing course one, Tom acknowledged the dotted blue lines: *"So, the two blue Xs by the dispenser thingy. I think each one of these trails of blue dots leads to a place where one of us has to stand."* After executing a few moves to identify how they can both get up to the places they need to be, Tom found the first location that they need to stand and suggested Liz that they need to find a way to get her up there (referring the other high ledge). However, Liz seemed a little confused about the location and Tom had to explain again and point out the location where she needs to be. This might indicate that even after Tom pointed out the utility of the trails of blue dots, she could not comprehend how make use of the sensory element in this case. In another instance, in testing course two, as soon as they entered the testing room a crane lowered down a tower button across where the players were standing. Since Tom was exploring the room and looking somewhere else, this event was not visible on his screen. However, Liz saw the lowering down of the tower button but did not react to it other than just looking at it.

Amongst the sensory stimuli elements provided in testing course two, Tom only noticed and incorporated audial cues into his strategy. For example, even though there were blue dotted lines leading from a tower button to a sidewall that clearly indicated that pressing the button will activate the sidewall, he overlooked this detail and just tested out what would happen if he hits the button.

> *Tom: "What happens if we hit the button. (He pressed the button and the sidewall moved out of the way.) That gets out of the way. (Ticking noise occurred) Oh but not for too long."*

In this example Tom indicated his willingness to try things out without knowing what it would result with. Because of the consistency of the operational rules throughout the game, he might have known that pressing a button would not penalize him.

Since pressing a button does not have any bad consequences, the players did not feel obliged to figuring out what it causes beforehand especially when faced less challenging problems. In testing course one, they had to integrate the dotted blue lines to help them solve the parts of the puzzle (identifying a mid-state they need to be in), but in testing course two the dotted lines were merely helping them since they did not need to understand what the button does without pressing it. Also in testing course five, Tom took an experimental approach to understand what the floor button was supposed to do. Tom: *"What happens if I step on this?"* This maybe because the dotted lines were leading towards a regular looking wall, which was not clear to the players in terms of the consequences of pressing that specific button.

Liz's misconstruction of the provided sensory stimuli elements continued on other occasions. For example in testing course three Liz went through a blue colored force field forgetting that it would erase her portals. When Tom tried to teleport using her portals they both realized that her portals were not there anymore.

> *Liz: "Oh what happened?" Tom: "Oh so if you walk through the blue wall there your portals disappear."*

At another testing course, after being exposed to it several times in previous testing course, Liz noticed that there was a blue shield field in between the forever-falling portals and reacted to it.

> *Liz: "Wait, why is there a little screen over there?" Tom: "That just means that whoever is falling can't have any portals out. That's the blue wall you keep seeing that erases your portals."*

The sensory stimuli elements provided in this chamber sometimes confused Tom and Liz and led them to take unnecessary actions. In testing course four, after seeing an up arrow sign Tom said: *“We also have elevators maybe?”* They both jumped onto the portalable surfaces with up arrows and nothing happened. Liz realized: *“I think it is just a portal and we have to go up.”* A similar confusion happened at the end of the same testing course after they pressed the buttons and released several balls Glados informed players: *“Beginning juggling test in 3, 2, 1.”* Both Liz and Tom looked slightly perplexed. They decided to pick up all the balls and bring them with them to the next room. However, they should have noticed that the unique door design indicated that it was the end of testing course and they did not need any additional balls.

Overall, Tom and Liz incorporated the sensory elements provided in this chamber to their advantage and successfully solved all the puzzles faced. The main sensory elements they took advantage of were the dotted lines (when facing a challenging puzzle), tik-tok (clock running out of) noise, arrows, and wall displays at the entrance of each testing course. A list of sensory stimuli elements and the associated functional roles is provided in Table 13.

During this chamber Tom and Liz took advantage of sensory stimuli elements provided by the game in most cases. They examined the wall displays at the beginning of each testing course as they usually did in the first chamber. These wall displays informed them about what game environment elements they will have to interact during the testing course and helped them identify middle states and operators.

Tom: “I think we have to do more jumping from portal to portal.”

Liz: "We have a cube. Wait we have to hand the cube from one person to another"

Table 13

Sensory Stimuli Events in Chamber II

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
Visual	Directive	X and dotted Lines	A-P B-A A-E	Tom: "So, the two blue Xs by the dispenser thingy. I think each one of these trails of blue dots leads to a place where one of us has to stand."
		Arrows pointing up	A-P B-C B-P	Tom: "We also have elevators maybe? I will hop in one and you hope in the other one?" Liz: "I think it is just portals and we have to go up."
		Bulls-eye sign on the wall	A-P A-S A-I	Tom: "Oh OK so there is a target thing and if we aim our portal right on the target, the lever thing will shoot us."
	Informative	Distinct arrangement of portals	A-P	Tom: "And this might be that we need to jump from one portal to another"
Auditory	Informative	Ticking noise	A-I B-I	Tom: "What happens if we hit the button? (He pressed the button and the sidewall moved out of the way.) That gets out of the way. (Ticking noise starts) Oh but not for too long."
	Decorative	Glados jokingly telling them "Begin Juggling test."	A-P B-I A-I	Tom: "Now we have to get all the balls."

Notes. [a]A: Tom B:Liz / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

They also examined their game environment carefully when they entered the testing courses and incorporated some of the sensory elements into their shared understanding of the problem.

> *Tom: "So we have lots of water that we can't go in and portal places."* (Verbalizing their initial state with the help of visual sensory elements)
>
> *Tom: "So the two blue Xs by the dispenser thingy, I think each one of those trails of blue dots leads to a place where one of us has to stand."* (Identifying middle state with the help of visual sensory elements)

Tom: "There is a target thing and we just put one right here. If we shoot a portal right on the target, the lever thing should shoot us right in." (Identifying an action with the help of visual sensory element)

Tom: "So eventually we want to end up there (Looking at the dotted lines.)" (Identifying the expected end state with the help of visual sensory elements) *Liz:" Button has to be right up there too." Tom: "It might be." Then he looks more closely and spots the button. Tom: "Yes, there it is."*

One of the new game elements introduced during this chamber, flinging action, also resulted with the introduction of more subtle visual elements such as angled portalable walls, or two portalable walls that stand horizontally parallel to create forever falling action. The team was successful at acknowledging these slight sensory elements and incorporating them in their joint problem solving process.

Tom: "That angled platform I think we have to come shooting out of."

As soon as Tom turns around and sees portal platforms facing each other one on top of the other they both realize what they have to do. Tom:"Ohhh ohh." Liz: "So there over there and shoot" (pointing with her fingers towards the portal platforms) Tom: "Hang on. So I think what we have to do is put two portals, one there and one there. And you get falling really fast between them and come out of that portal. Does that make sense?" Liz:"Hmmhmm."

Tom: So one of us has to stand on there (Floor switch) Liz: There is where the cube is. Tom: So next question is how do we… Ah there is another one of the falling forever things.

Tom: "Here is the falling forever thingy."

Liz and Tom: "Another one." Liz: "There is the target." Tom: "And there is the angled one." Liz: "And it will shoot us up there."

However there were some exceptions in taking every sensory stimuli event into account while they were building an understanding of the problem through identifying middle states or operators. As mentioned before, in testing course two, as soon as they entered the testing room a crane lowers down a tower button across where the players are standing. Since Tom was exploring the room and looking at somewhere else, this event was not visible on his screen. On the other hand, Liz saw that tower button was lowered down, but she did not say anything about it. A sensory element that catered to both visual and audial senses was ignored during that moment. This might be due to the fact that the function of buttons and the procedural rules about them were clear to the team members. Therefore, maybe she assumed that the whole action of lowering down a button from the ceiling was unnecessary to speak about since even if Tom sees the button across from them he will know that they will have to reach to it.

There were only a few occasions where the team reacted to the audial sensory elements. One of these occasions was in testing course two; after Tom pressed a tower button a short ticking noise was heard. He indicated his understanding of the ticking stimulus, that whatever the button was doing it was for a short time, with his statement. *“Oh but not for too long.”* Later on, with the help of this audial element, they knew what some of the middle states and operators were. In another occasion Glados made a sarcastic comment about juggling after several balls were dropped down from the dispenser. Even though the team only needed to use one ball to open the door, this comment made by Glados caused them to identify unnecessary actions and middle states. This shows how some sensory stimuli led the team to make incorrect assumptions.

Overall, Tom and Liz made an extensive use of visual sensory stimuli elements provided during this chamber as they usually do. They also incorporated audial clues when they were provided, even when the audial sensory elements were given not as a clue but more so in a sarcastically mocking nature.

Clarity of the goals and rules.

Based on the questionnaire that aimed to measure the players' perception on the clarity and easiness of understanding the level goals and the rules, Liz seemed to be a little less clear about the goals and the rules of this chamber compare to Tom (Table 14). This was also observed during their gameplay. For example throughout the game play Liz was not clear about how the blue force fields functioned in a constraining way, and the concept of flinging, gaining momentum through falling in between two portals, appeared to confuse her slightly.

Table 14

Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Tom	Liz
Testing Course 1	26	18
Testing Course 2	27	24
Testing Course 3	24	28
Testing Course 4	28	18
Testing Course 5	25	8
Testing Course 6	24	26

As mentioned previously, clear and repetitive representation of the goals of this game made it easier for Tom and Liz, as a team, to able to identify them even though as an individual Liz was struggling to understand the goals and the rules of the game. Tom and Liz always identified the final state of the problem before they took any action in the game. Through conversing and experimenting they were able identify most of the middle states and actions that helped them during their construction of the shared understanding of the problem.

> *Liz: "Where do we have to end up? Tom: "Over there I think."* (Final state –end goal)
>
> *Tom: "I think we have to come shooting out of a portal that is right up there really really fast to make it to that distance."* (Actions)
>
> *Tom: "So one of us has to stand on there (Floor switch)" Liz: "There is where the cube is." Tom: "So next question is how do we… Ah there is another one of the falling forever things."* (Identifying middle states and actions)
>
> *Tom: "It looks like the cube has to go in there.* (Final state) *And then we also have elevators maybe?* (Actions) *I will hop in one and you hope in the other one?" After getting on the platform that they though were elevators, they realize that they are not. Liz: "I think it is a portal so we got to go up"* (Through discussion and experimentation they identify the right middle states and actions.)
>
> *Tom: "I have to get up there* (Final state) *which means you are going to have to put your portals on where mine are* (Middle state)*, and I am going to have to go put mine on where I can spring.* (Middle state)"

Tom: "I think you have to end up here now. (Final state) *If you go back to the springboard thing* (middle state and actions) *hopefully you will just come here fine. I don't know what is over there." After Oranges reached there, Tom: "So we both have to end up there.* (Final state)" *Tom: "Is there anything where you are to put a portal.* (Trying to identify middle states and actions)" … *Tom: "we need to figure out how I can get there.* (Trying to identify actions)" *Liz: "I will have to make a portal somewhere for you.* (Trying to identify actions through discussion and exploration)"

Tom walked over to his last portal and looked down and saw the jumping board. Tom: "Oh hang on." and he jumped into his portal onto the jumping board that shot him right up. (Identifying actions through experimentation)

In addition to providing new procedural rules such as falling between portals or jumping on a springboard to gain velocity, the consistent structure of the procedural rules with slight variations continued to be observed during this chamber. When Tom and Liz first faced the necessity for the flinging action to achieve their end goal, they were able to quickly discover the action that needed to be taken due to both visual sensory elements provided as a feedfront and Tom's previous gaming experience with *Portal 1*. However, they were also able to quickly adjust their understanding of procedural rules on flinging action to adapt it similar problems they faced. In room four, they are using the flinging action to shoot up instead of shooting across a large gap.

Tom: "The button is really high up. So what we have to do is fall for a really long time, and then instead of falling down, we go all the way up."

At some cases it was observed that Tom and Liz were not sure about what pressing buttons would result with. However, since there were no punishments or drawbacks for pressing a button or floor switch without knowing what it does, they did not worry about it. Therefore it can be assumed that they had a generic understanding of one of the procedural rules of the game: “If you press a button or a floor switch, something useful will happen, and there is no chance of something bad coming out of pressing buttons.”

As for operational rules, Liz still seemed less clear about how some of the game environment elements constrained their actions. As mentioned before, her confusion regarding the blue force field was a significant exemplar of this situation.

> *Liz:" You can't go through there (pointing towards the blue force field)?" Tom: "I can't, but you can. If I walk through there it will erase my portals."*

Another example where the operational rules were not obvious to the team was in testing course four when Tom tried to slow down Liz’s forever falling cycle by stepping into the same portal she was falling into, which resulted with her character’s death. However, other than these exceptions, in general the team was able to understand what they can or cannot do during the game through examining the wall displays and though their past game experience.

Within Case 2 - Group 2 (Dan and Amy) Playing Portal 2

Dan was one of the most experienced gamers amongst all the participants of this research, and he was not familiar with the main concept of the Portal game. Conversely, Amy, who is an advance-intermediate level game player, had mentioned that she knew how the Portal gameplay worked as she sometimes watched her friends play the game. However, she also expressed her concerns with the game mechanics and how she might not be able to perform well.

Amy: "The physics of this game is kind of what I mind, but we will see how I do. There is one particular kind of mechanic that we have to do sometimes that I just can't."

The team started the gameplay with little interaction and conversations, but as they moved along in the game space they became more conversant. Unfortunately Amy had a low visibility issue at earlier sections of the game due to the direct sunlight hitting on her side of the projector screen. She reflected her frustration about this issue throughout the first session, but she was able to complete the missions successfully with the help of her team mate. There was also a malfunction in the recording system during testing course one. Therefore, the researcher was not able to obtain the gameplay recording data for this section of the game.

Dan and Amy played *Portal 2* over two sessions, completing the tutorial, chamber one and chamber two of the game. During session one, the team was able to complete the tutorial, the first chamber, and one testing course in chamber II in approximately two hours. During second session the team completed the rest of the testing courses in chamber II in approximately 1.5 hours.

Tutorial chamber.

While they were both trying to get accustomed with the game during this level, it was observed that Amy had a harder time than Dan in getting used to the gameplay. At the beginning of the tutorial they did not participate in any conversation, and moved around the game world individually. While Dan was moving forward quickly, Amy was having trouble with identifying what she needed to do by herself. Until Dan hit a barrier that needed to be overcome with the partner, he did not initiate any conversation to help Amy. However, even after completing his part of the game goal while he was helping his partner, Dan still executed random actions in the game world such as shooting portals at random locations (portalable and unportalable) or teleporting back and forth from his portals. Even if they were slightly dysfunctional as a team at the beginning, they became more talkative during the middle of the tutorial and completed this level in 13 minutes 23 seconds.

Collaboration and joint problem space.

The team chose not to collaborate at most of the times during this level, unless the game required them to do so. The divided up environment structure of the tutorial level allowed them to work individually until they reached at certain parts where they had to work together to overcome the obstacles. As mentioned previously, while Dan mainly executed actions lavishly by himself, Amy was not moving around as much. This might be due to the fact that her character kept falling into acid water and died a few times as she could not see the dark parts of the screen well.

Although the discrepancy between their gaming expertise levels was not too high, there were still differences in their game play styles. While as an avid game player Dan was shooting at everything and probing every game item without verbalizing a strategy (61%), Liz was thinking about the problems through talking about them out loud without executing actions as much (39%). This difference in their game play styles influenced their collaboration throughout the game. Dan mostly executed actions without consulting his team mate, but he also explained what needed to be done for Amy when she was stuck. They both scarcely proposed any ideas before they took actions; instead they just executed actions until they found a solution to the problem. For example in room six, where they had the most idea exchange and conversations, Amy came up with part of the solution without even proposing her idea first. However, it was also observed that as soon as she took the right action, Dan knew what he needed to do for his side of problem solving.

Overall this level did not challenge them or require them to work together, and this reflected on the distribution and frequency of the functional roles that they assumed during the gameplay (Table 15). The team spent most of their time executing moves and explaining what moves needed to take place (Total of 83% of all the actions), and least amount of time proposing, implementing, and contesting ideas (Total of 17% of all the actions).

Of the times they initiated a collaborative effort to solve the problems, they were showcasing an almost balanced total number of functional roles excluding execution and explanation. While Amy was contesting and implementing ideas more, Dan was proposing slightly more number of ideas. Overall, the team solved through the puzzles of this level mostly without proposing and with individual action taking.

Table 15

Frequency of Functional Roles Assumed During Portal 2 Tutorial Chamber

Functional Role	Dan		Amy		Total	
	N	%	N	%	N	%
Execution	78	60.94	50	39.06	128	76.65
Implementation	5	41.67	7	58.33	12	7.19
Proposal	4	66.67	2	33.33	6	3.59
Contestation	1	25.00	3	75.00	4	2.40
Rejection	0	0.00	0	0.00	0	0.00
Acceptance	1	25.00	3	75.00	4	2.40
Modification	0	0.00	1	100.00	1	0.60
Reasoning	2	100.00	0	0.00	2	1.20
Testing	0	0.00	0	0.00	0	0.00
Explanation	10	100.00	0	0.00	10	5.99
Total	101	60.48	66	39.52	167	100.00

Influence of game design elements on collaborative problem solving.

Challenge.

Both Amy and Dan felt not very much challenged by the tutorial level as they both scored 7 as their perceived challenge levels. Although they both indicated that the level of challenge was fairly adequate for them, it was observed that they were easily able to go through the puzzles of this section. Although, at the beginning of tutorial Amy was struggling, she was quickly able to adjust herself and go through the rest of the testing room easily without Dan's help. The low levels of challenge, combined with the separated room design of the gameplay during this section, did not steer them towards a collaborative approach frequently.

Sensory stimuli elements.

Unlike the previous team, Amy and Dan paid less attention and showed no reaction to the verbal feedfront sensory elements. During the tutorial the game provided several feedfront sensory events through the voice of Glados. For example when Dan entered the second room he took action and reached the expected location in the room before Glados could finish up her speech explaining what they needed to do. On the other hand, it is important to note that when Dan entered the second room, Amy was still in room one trying to figure out the next step. She seemed confused especially after hearing Glados say that they needed to portal themselves up to a ledge.

> *After teleporting herself back into the room one Amy says: "But I am back where I started. I am trying to get up top right." Dan: "Right." After getting her bearings back Amy: "I am trying to get up there (looking at a window up in the ceiling)?" Dan: "No. I think that you want to go right through there (door 1). You want to walk straight through there." Amy: "Well, I did." Dan: "And you went through your portal because you have one there (in room one)." Amy: "Because I have one here." Dan: "You want to get up to hmm that's where I am right now." Amy: "Right here (Still looking at the same window)?" Dan: "I think so.[ON: He must have not paid attention what she was pointing at]" After Amy tries to shoot a portal in the same location she was looking at Dan: "You can't. You got to walk straight through there, you know where you have your portal up there." Amy: "right." Dan: "You need to make one on top of the ledge up there. There is a ledge on top of that portal that's what I did t get up here." Amy: "A ledge on top of here (Still in room one staring up to the ceiling)?" Dan: "No. Just go straight." After Amy goes into the second room, Dan: "Do you see the white ledge on top of the portal right there." Amy: "Oh oh there. That ledge." Dan: "So make a second portal up there."*

As we can see here, Amy was confused by the auditory feedback that they received about portalling to a ledge. Since the timing of the sensory elements was too early (before she reached the second room), this created a confusion for her. However, with the help of her teammate she was able to complete the steps necessary. This confused state and her reaching out to Dan for help forced teammates to have a conversation and be supportive of each other. Even if it was not designed to have this effect on the players, with the unexpected help of this sensory stimuli Dan and Amy started to work as a team.

Dan in general did not show any verbal reaction to any of the visual sensory elements provided during this level. However, he did probe everything that was different in color or shape through walking towards them and shooting them in the game environment. At this level of the game, it was not clear that Dan had an understanding of how the sensory elements of the game worked as a feedback or feedfront mechanism. He ignored the fact that the game does not allow players to place portals in dark colored walls and instead he kept shooting at every direction until one of them came up with a solution. Both Glados and Amy reminded Dan about only being able to shoot portals on white colored walls. Unlike Dan, Amy looked at some of the floor signs and tried to understand what they meant.

Amy: "What does this tell me?" (While looking at a sign on the floor) "Do not drink this water."

This shows that Amy attended to informative visual sensory stimuli. She verbalized her understanding of them. Assuming that Dan heard what she said, this could have helped them develop a common understanding of the problem.

However, she failed to listen to another verbal feedback given by Glados in room six when Dan pressed the tower button and a cube fell off to the acid water and disintegrated. Glados said: “Nice catch Orange.” (Indicating that she should be catching the cube that was released by Dan) As she was still looking at the floor sign, Dan told her that she should get close to the ledge to catch the cube which she corresponded.

Another visual sensory element that helped them solve the puzzle was the openings in the window that was dividing up their room. While they were trying to figure out how to get the cube across a field of acid water and a force field, the opening in the glass separator wall captured their attention.

Dan: “They gave me this opening there must be some type of way.”

His reaction to the opening in the glass wall instigated Amy and she started to jump in front of the opening with the cube in her hand, and it was during one of her tries of jumping that Dan caught the cube out of her hands through the opening.

Dan: “I got it, but what do I do with it.” Amy: “I have no idea.” Dan: “Can I throw it to you over there? (Pointing at another opening on the other side of the glass wall)”

Overall in this section for the game, it seemed that both teammates were playing the game more individually then collaboratively they did not pay attention to most of the sensory stimuli elements while solving the problems.

Clarity of goals and rules.

As one of the main premises of the tutorial session is to get players accustomed with the procedural and system rule, both Amy and Dan learned about the goals and rules after a little bit of experimentation. For example, when the first time Dan encountered a button he was not sure what it did, he pressed the button to see what would happen. This allowed him to build an understanding of this procedural rule (i.e. you will get a cube when you press a button). When Amy tried to walk through a force field while holding a cube, the restrictive operational rule disintegrated the cube, and after that she knew she could not take the cubes through the force fields. Also when Amy saw a red floor switch that had an inward-looking shape, she thought she could step on it and activate the door open. However, when nothing happened after she stepped on it she realized she needed a cube to activate this switch. These newly gained understanding of the game rules helped them shape their individual problem spaces and through sharing their understanding of the game rules they were able to develop their joint problem space.

> *Amy: "I can do this" After stepping on the red floor switch, nothing happens. "But I need the cube still, which means I need a portal to get through this (force field)"…"So I need to get the cube through here, and put it on the button, but the cube will disappear if I carry it over there (looking at the force field)."*

Dan's experimental behavior with his surrounding and poor judgment on the system rules continued throughout the tutorial session. Due to his high level of experience with gaming, he might have not exhibit any attempt to understand this game's specific rules as probably his previous experiences given him the sense that he could complete any easy level with perseverant action taking such as shooting everything or pressing every button in the game.

The repetitive end goal of each room was simply to move forward to the next room through a combination of game actions. During the tutorial, although not verbally stated, it was observed that Dan had a clear understanding of what the goal of each level was. He kept moving forward at every opportunity, even leaving his team mate behind. However, Amy, at the beginning, did not seem to comprehend that she needed to move to the next room, as she was still examining the room one for a solution when she needed to get to room two. They eventually built a common understanding of the goals through conversations.

Chamber I (Team Building).

Dan and Amy quickly adapted their previously gained gaming skills into this section of the game and successfully undertook the challenges given in chamber one during the rest of the session. During chamber one it was observed that Amy was not struggling as much as in the previous level and Dan was getting a hang of the concept of the game with a few exceptions. They formed equally balanced group dynamics and communicated more frequently during this chamber which indicated a growing collaborative effort. Amy was still feeling incompetent at performing certain game mechanics that required precision and speed such as aiming a laser beam to a specific point, which necessitated Dan to take over. It is important to note that they differed from other teams in their approach to problem solving, as they employed more of a trial-and-error method instead of strategizing their moves in advance. Nevertheless, as a team they were able to work well together and completed all of the testing courses with average time of 12 minutes 46 seconds with testing course three taking the longest time (28 min 47 sec) and testing course five taking the shortest time (5 min 6 sec).

Collaboration.

Although they started their gameplay with more individual action taking and showcased some elements of collaboration at the beginning, they initiated more conversations and interacted with each other more during this chamber. It was observed that they were both equally contributing to the collaborative problem solving process and assuming various functional roles throughout the chamber. As mentioned before, instead of discussing their ideas before they took any actions, this team utilized a trial-and-error approach to most of the problems. They individually probed the game objects and if no solution is quickly identified by either one of them, then a conversation about the problem would take place to find a solution together. This approach was also reflected in their functional roles as the frequency of the role *Execution* was lofty (44% of all roles assumed).

The balance in the distribution and frequency of their functional roles during this chamber can be observed in Table 16. Amy and Dan partook in joint decision-making activities 56% of the times (N=274). Their joint decision-making activities included proposing ideas (N=45), implementing ideas (N=168), modifying a proposed idea (N=16), contesting a proposed idea (N=6), accepting a proposed idea (N=9), stating reasons behind an idea (N=4), and testing an idea (N=26). Although Dan proposed more ideas 67%) than Amy (33%), overall it was observed that their contribution to generating the right solutions to the problem was almost equally essential.

Table 16

Frequency of Functional Roles Assumed During Portal 2 Chamber I

		Testing Course 2		Testing Course 3		Testing Course 4		Testing Course 5		Testing Course 6		Dan Total	Amy Total	Total
		Dan	Amy	Dan	Amy	Dan	Amy	Dan	Amy	Dan	Amy			
Execution	N	9	5	36	11	14	5	4	5	93	32	156	58	214
	%	64.28	35.71	76.6	23.4	73.68	26.32	44.44	55.56	74.4	25.6	72.9	27.1	43.76
Proposal	N	8	1	10	6	4	3	5	2	3	3	30	15	45
	%	88.89	11.11	62.5	37.5	57.14	42.86	71.43	28.57	50	50	66.67	33.33	9.2
Implementation	N	11	17	49	25	19	16	10	7	8	6	97	71	168
	%	39.29	60.71	66.22	33.78	54.29	45.71	58.82	41.18	57.14	42.86	57.74	42.26	34.36
Modification	N	1	2	4	5	2	0	1	0	0	1	8	8	16
	%	33.33	66.67	44.44	55.56	100	0	100	0	0	100	50	50	3.27
Contestation	N	0	2	1	0	0	1	1	1	0	0	2	4	6
	%	0	100	100	0	0	100	50	50	0	0	33.33	66.67	1.23
Rejection	N	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0
Acceptance	N	1	4	0	2	0	0	0	2	0	0	1	8	9
	%	20	80	0	100	0	0	0	100	0	0	11.11	88.89	1.84
Reasoning	N	1	0	1	0	0	0	2	0	0	0	4	0	4
	%	100	0	100	0	0	0	100	0	0	0	100	0	0.82
Testing	N	6	2	7	8	0	0	1	0	1	1	15	11	26
	%	75	25	46.67	53.33	0	0	100	0	50	50	57.69	42.31	5.32
Explanation	N	0	0	1	0	0	0	0	0	0	0	1	0	1
	%	0	0	100	0	0	0	0	0	0	0	100	0	0.2
Total	N	36	34	109	57	39	25	24	17	105	43	313	176	489
	%	51.43	48.57	65.66	34.34	60.94	39.06	58.54	41.46	70.95	29.05	64.01	35.99	100

Joint problem space.

Although not often, Dan and Amy verbally indicated their effort to create a shared understanding of the problem space during chamber one. They did not always look around to identify their end-goal when they entered a testing chamber. However, they were both aware that there was a door that they had to open somehow to complete the testing course. Therefore, they mostly focused on identifying initial and middle states and actions. As they moved along the testing courses of chamber one, they became more conversational about the initial state of their problem environment. They both quickly explored the testing courses as soon as they entered it and told their partner about the game objects they see in the room:

Amy: "So we got a cube." (Identifying a problem state)

Amy: "More laser beams, and a button." (Identifying a problem state)

Amy: "Huh there is a button with a portal wall, but how to get there?" (Identifying a problem state and pondering about possible actions)

Amy: "So we have a laser. We have a portal wall." Dan: "And we have a giant room over here." (Identifying a problem state)

Dan: "We have portal walls here." Amy: "And there is a cube." (Identifying a problem state)

Amy: "So we have a cube and a laser." Dan: "We got a laser receiver right there." Amy: "Floor of death." Dan: "We got another laser thing over there (looking at a laser receiver). Laser thing over there (turning around and looking at another laser receiver)." (Identifying a problem state)

Here we see examples of both teammates identifying and verbalizing initial problem states by pointing out the game objects that are around them in different testing courses. This type of conversation took place every testing course and helped the team to develop a common understanding of the problem.

They were also successful at identifying the middle states and how they can operate through states, and this was occasionally reflected in their conversations.

> *Dan: "Now there is two going, we have to go get the other two."* (Identifying a problem state) *Amy: "Ok got it." Dan: "Where are they?" Amy: "So there is two on top and two down below. So one of us has to do..." Dan: "We both need to do two. So would you get up top, the one right in front of me, using your portals?"* (Identifying a possible actions and problem states) *Amy: "Yup." Dan: "So I guess the best thing to do is to..." Amy: "I think do it (meaning pressing the button) and each jump down and do the one below."* (Identifying a possible actions and problem states) *Dan: "OK."*
>
> ---
>
> *Dan: "So we have to hit to this one (Second Switch) too right?"* (Identifying a possible actions)*Amy: "Right. Do we have another cube?"* (Identifying problem states) *Dan: "I think we got to use this laser still."* (Identifying a possible actions) *Amy: "So instead of coming through with that angle we need to come straight through (Talking about how portals are directing the laser beam with an angle)"* (Identifying a possible actions and problem states) *Dan: "Possibly." Amy: "I think we got to get to this button first."* (Identifying a possible actions and problem states) *Amy: "So what is this thing up here?" Dan: "I think we need to hit it. Both*

needs to be hit by the laser light." (Identifying a possible actions and problem states) *Amy: "Oh i bet it is true." After getting all the laser beams directed to the switches, Amy: "I am not sure what that opened." Dan: "You see the door up there. That's what it opened."* (Identifying problem states) *Amy: "Oh I see, the second one lowered the platforms so we can get to the door."* (Identifying a association between an action and a problem state)… *After many tries to distracting and attempting to grab turrets, Dan suggests that they should maybe move the laser a little bit to the side of the portal so it doesn't block him. Then, Amy proposes: "Maybe, you can rotate it and laser the turrets?"* (Identifying a possible actions) *Dan: "Wow." Amy: "We are such idiots." Dan: "That is upsetting."*

Amy: "So we got to get that cube obviously." (Identifying a possible actions and problem states) *Amy: "So we are going to want to come out over here. Oh I see one goes down one goes up, so it is a timing thing."* (Identifying a possible actions and problem states, and associations) *Amy: "So I am thinking that the receivers going to raise or lower this platforms"* (Identifying problem states)

In these three distinct examples of conversations that took place during different times in this chamber, we can see how Dan and Amy collaboratively identified and discussed about the problem states and possible actions that they could take. This allowed them to create a joint problem space and converge on solutions together.

Overall both team members portrayed a reasonable effort to develop a joint problem space through discussing their individual understanding of the problem states, and the possible actions.

Influence of game design elements on collaborative problem solving.

Challenge.

The participants' perceived challenge level for each testing course of this chamber, along with the frequency of their functional roles, is reported in Table 17.

Table 17

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Testing Course 2	Dan	3	9	8	11	1	0	0	1	1	6	0
	Amy	6	5	1	17	2	2	0	4	0	2	0
Testing Course 3	Dan	16	36	10	49	4	1	0	0	1	7	1
	Amy	12	11	6	25	5	0	0	2	0	8	0
Testing Course 4	Dan	5	14	4	19	2	0	0	0	0	0	0
	Amy	6	5	3	16	0	1	0	0	0	0	0
Testing Course 5	Dan	5	4	5	10	1	1	0	0	2	1	0
	Amy	6	5	2	7	0	1	0	2	0	0	0
Testing Course 6	Dan	6	93	3	8	0	0	0	0	0	1	0
	Amy	7	32	3	6	1	0	0	0	0	1	0

As it can be seen from the Table 17, the team worked more collaboratively during testing course three and testing course two. One reason the team had more collaborative functions displayed in testing course three was due to its difficulty experienced by this team. As the challenge levels were increased, for both the teammates (presented in the

Table 17) the team resorted to a more collaborative approach. As this testing course was also more complex in the way that a series of composite solutions were required to complete it, they had to propose and test various ideas before they could identify the right solutions. Asides from the high frequency of the functional roles due to the extended time and effort spent in this testing course, the diversity of the assumed functional roles was also noteworthy.

In testing course two, although the perceived challenge levels were not too high, the group displayed a variety of functional roles which might be due to the marginally high gap between the reported challenge levels. Amy felt more challenged during this testing course, and did not propose as many ideas as Dan. It was observed that he was more in control of the problem solving activity, and portrayed various functional roles.

In other testing courses, the team mainly resorted to trial-and-error approach at the individual and the team level, where they performed many actions without discussing it. Especially in testing course six, Dan and Amy executed more individual actions than any other testing course. The individual action taking was to a point where Dan would be trying to shoot portals at every single square inch of a room, or trying to probe any game object available in the room. Amy, not as much as Dan, would also individually interact with the game environment during this final testing course until one of them found the game object that was necessary to activate to get to the solution. Unlike testing course three, the team did not have to find a composite solution but rather identify a series of disjoint solutions such as finding a way to get out of the railing, and then finding a way to open the door while timing their actions right. Interestingly they did not rate this testing course very challenging, even though they spent significant amount of time trying to identify a solution by executing individual moves.

For Dan and Amy, the testing course three was the most challenging level of this chamber. During this testing course, Dan and Amy found the overall solution of the problem after a few tries, but they had a hard time identifying a part of the solution that was crucial for them to be able to complete the testing course. They had to find a way to disable or avoid the turret robots. The rules of how to get rid of them was not very clear to them and they had not encountered a similar gameplay in earlier sections of the game. However, Amy had an idea about how to disable the robots based on her previous knowledge of the first Portal game. As a group they tried to implement her solution to the problem in various ways, which resulted in failure and frustration. They proposed and implemented several ideas around how to reach the robots, but none of them worked, until Amy suggested that they should use the laser beam to try to disable the robots.

> *Dan: "The question is how do we get the other side?" Amy: "Alright so here is what I know from the previous portal knowledge. If you can grab one of the turrets it shoots the other turrets, if even knock down one of the turrets it shoots the other turrets. So that it is what I was trying to do when I was coming out of that one (portal), but I couldn't do it fast enough." Dan: "Right." Amy: "Maybe you can." Dan: "So this thing has to be distraction." Amy: "Yeah if you go try to grab them I will distract them.*

During this challenging testing course, they explored their game environment more and conversed about problem states and actions more than other testing courses. Even though challenge of this testing course was only due to a partial difficulty that they had to face, it still required them to construct a better shared understanding of the problem.

Other than testing course six, they communicated well and shaped their joint problem space for the rest of the low to medium level challenging testing courses. They identified states and actions and shared their thoughts with each other. Testing course six was also reported as relatively more challenging compare to most of the other levels, possibly, due to the unclear goals of this testing course. During this testing course, Dan and Amy mostly worked as individuals to create their own understanding of the problem and then shared certain important aspects to generate a shared understanding. They continued to explore the testing course six individually with occasional conversations to share their thoughts until they found the necessary game objects (wall switches) to complete the puzzle. The collective process of building an understanding of the problem only occurred towards the end of the testing course. Unfortunately, the unclear goals of this testing course did increase the challenge level of the testing course, and did not augment the collaborative problem solving process.

Sensory stimuli elements.

Amy and Dan did not react to most of the audible and visual sensory elements provided by the game in an observable way. They did not look at any of the visual displays that were provided at the beginning of each testing course. They did not take the blue dots into consideration most of the time while they were trying to solve the puzzles. They did not keep silent so they can listen to what Glados has to say many times. In general the team ignored most of the sensory stimuli elements or failed to converse about it even if they noticed some of them, unless they were not able to solve the problem immediately. Even though overall it was not obvious to observe what kind of train of thought was going on in their minds regarding the sensory elements, there were some moments where the influence of sensory elements on their collaborative efforts were prominent. Here are the conversations that took place during some of those moments:

> *In testing course two, Amy saw an orange colored floor switch that was round shaped which resembled the previously encountered red round floor switches that they had to step on. Amy then thought that they can step on it to activate something, but realized that she was not accurate. Amy: "We got a button." She steps on it. Amy: "Sort of? No we don't have a button." After Amy's failed attempt to step on the button to activate it, Dan tried to shoot it as it was his approach to anything he saw in the game environment.*
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> ---
>
> *Dan: "What are those symbols up here?" Amy: "Triangle, x, dot and a moon. There is triangle and the moon, and I think x and the dot is over here." Dan: "I think these are all buttons up here. Let me see what happens if I try to go up there." When Dan tries out pressing one of the tower buttons ticking noise appears. Amy: "Ops something is opened for a limited time." Dan: "I think we have to press all those four buttons within that time." Amy: "You think these are actual buttons? (After she walks up to a symbol, she sees the button behind it) Oh I see."*

They also noticed the fact that some moving objects should have a role in the path of finding a solution. In testing course three, when their numerous attempts to go over to the room that had turret robots failed they came to a conclusion that panel that move based on stepping on a floor button should have a purpose:

Dan: "What are the points of these things (moving panels) right here? What are these doing for us?" Amy: "So pushing the button brings them down. Maybe pushing the button distracts them, so maybe if you push the button when I come through over there? Maybe, they won't shoot me immediately and I can pick them up and make them shoot at each other (possibly a previously observed behavior)" After stepping on the floor button Dan: "I mean this (moving panels) has to do something with it too." Amy: "Right." Dan: "I don't know. Seems like every time I put this up they shoot at it."

Amy: "Alright, now we are back to the 'there has to be a reason for this (moving panels'."

The only time that they outspokenly observed and utilized the dotted lines that indicates the relationship between game objects was in testing course three when the team ran out of ideas and their actions were not yielding successful results.

Amy: "What did lighting that thing up do anyway?" Dan: "I am not really sure. What is the difference between lighting it up and not lighting it up? Can you see?"

Amy: "It turns the light (dotted lines) over here to blue. Something is open."

There was also a time where a sensory stimuli element led the team towards a wrong strategy. In testing course three, while Dan was trying to sneak up on the turret robots as Amy was trying to distract them with stepping on a button, Dan walked into the room with turrets. A text “Jump” and symbol (X) became apparent on the screen to indicate the player that (X) button is used to jump in the game and they would need to incorporate that action. However, this sensory stimuli element was presented at a wrong time while the turret robots are still trying to shoot them, and meant to guide the players in that room after the turret guns were disabled. Since their unconventional approach to get rid the turret robots were not right and he was not supposed to be in that room, the game still presented the ‘(X) Jump’ text which confused the team:

Dan: "Why did it tell me to jump right now?" (Indicating the jump text appears on the screen) Amy: "I don't know. Oh maybe if I stay here (on the floor button) and keep jumping up and down, it will keep them (turret robots) confused?"

On the other hand, in testing course six a visual sensory stimuli element directed them toward the right solution. When Dan pulled down the wall switch, a set of pictures and text appeared to instruct how to ‘hold down for countdown’ which he performed. However, only being able to find one switch and counting down for one switch did not make too much sense to Dan, and so he decided that this was a pointless feedback from the game to be only used during online interactions with team mates. However, Amy pointed out that it might indicate something else:

Dan: "I think it is just a gesture thing." Amy: "But the fact that it popped out for both of us makes me think that it is a timing thing (that two of us have to do at the same time)."

As mentioned previously, it was not easy to observe the influence of the sensory stimuli elements on this team’s assumed functional roles as they either did not notice some of the sensory elements, or chose not to talk about it. For example in one occasion after seeing a video on a wall that indicates inserting a disc into a drive with the text ‘insert disc’ next to it, neither of the team mates said anything about it, with the exception of Dan trying to shoot a portal on it – which he did to almost every game object. The verbalized acknowledgement of it came out later on which indicated that some obviously presented sensory elements were observed by these participants but not talked about:

> *Amy picks up the disc saying: "Oh look at this, and there is a thing over there that wants me to insert the disc."*

A complete list of all the sensory stimuli incidents that hinted a direct influential impact on the functional roles is presented in Table 18 below.

Table 18

Sensory Stimuli Events in Chamber I

Sensory Stimuli Elements			Functional Role Triggered*	Example Participant Reaction
Visual	Directive	Symbols on wall and buttons	A-P A-T, A-T, A-T, A-T	Dan: "What are those symbols up here?" Amy: "Triangle, x, dot and a moon. There is triangle and the moon, and I think x and the dot is over here." Dan: "I think these are all buttons up here. Let me see what happens if I try to go up there."
		Moving panel	A-E, A-E	Dan: "So what happens when I put these (moving panel) up? What is going on here? Is that a portal wall?" Amy: "No"
		Moving panel	B-P B-I, B-I, A-T, A-T, A-T, A-T, A-T, A-M B-I	Dan: "What are the points of these things right here? What are these doing for us?" Amy: "So pushing the button brings them down. Maybe pushing the button distracts them, so maybe if you push the button when I come through over there? Maybe they won't shoot me immediately and I can pick them up and make them shoot at each other"
		Dotted lines	A-E	Amy looks at the dotted lines and follows them to see where it reaches in room 3.
		Dotted lines	B-P B-T, A-I	Amy: "What did lighting that thing up do anyway?" Dan: "I am not really sure. What is the difference between lighting it up and not lighting it up? Can you see?" Amy: "It turns the light over here to blue. Something is open."
		"X-Jump" on screen	B-E	Dan: "Why did it tell me to jump right now?" (indicating the jump text appears on the screen) Amy: "I don't know. Oh maybe if I stay here (on the floor button) and keep jumping up and down it will keep them confused?"
		"Hold for countdown" on screen	A-P B-C	Dan: "I think it is just a gesture thing." Amy: "But the fact that it popped out for both of us makes me think that it is a timing thing."
		Insert disc sign	B-E	Amy picks up the disc saying: "Oh look at this, and there a thing over there that wants me to insert the disc."

Table 18 (*continued*)

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
	Informative	Distinct shape/color of an object	A-E	Amy: "We got a button." Steps on it. "Sort of? No we don't have a button." Dan shoots at the same button after Amy get off it.
		Sparkles on the wall	A-P B-A B-I	Dan: "Maybe you put a portal where it is hitting the wall, you see where it is making sparks on the wall." Amy: "Yeah." Dan: "Right there."
		Sign on top of a button	B-E	Amy looks at the sign on top of the tower button, Amy: "what does this button say? Oh this button drops a cube."
	Decorative	Cameras	A-E	Dan: "What are these things?" He shoots at them.
Auditory	Informative	Ticking noise	A-S B-C A-E, A-P B-T	When Dan tries out pressing one of the tower buttons ticking noise appears. Amy: "Ops something is opened for a limited time." Dan: "I think we have to press all those four buttons within that time." Amy: "You think these are actual buttons? (After she walks up to a symbol, she sees the button behind it) Oh I see."

Notes. [a]A: Dan B:Amy / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

Although not taking all of them into account, Dan and Amy incorporated a selection of the sensory stimuli elements during constructing a shared understanding of the problem space. Their use of sensory stimuli elements was most prominent in testing course three when they were able to identify the middle states and the actions of the problem space with the help of visual and audial sensory stimuli elements provided.

Dan: "What are those symbols up here?" Amy: "Triangle, x, dot and a moon. There is triangle and the moon, and I think x and the dot is over here." Dan: "I think these are all buttons up here. Let me see what happens if I try to go up there (up to the ledge)."

When Dan tries out pressing one of the tower buttons ticking noise appears. Amy: "Ops something is opened for a limited time." Dan: "I think we have to press all those four buttons within that time."

Amy: "So if I push this one, is it going to tick at us too? Ok." Dan: "Now there is two going we have to go get the other two." Amy: "Ok got it." Dan: "Where are they?" Amy: "So there is two on top and two down below. So one of us has to do..." Dan: "We both need to do two. So would you get up top the one right in front of me, using your portals." Amy: "Yup."

Dan: "So I guess the best thing to do is to..." Amy: " I think do it (meaning pressing the button) and each jump down and do the one below." Dan: "OK."

In other testing rooms Amy and Dan occasionally made us of visual sensory elements provided by the game.

Dan: "Maybe you put a portal where it is hitting the wall, you see where it is making sparks on the wall." Amy: "Yeah." Dan: "Right there."

Amy: "So what is this thing up here?" Dan: "I think we need to hit it. Both needs to be hit by the laser light." Amy: "Oh I bet it is true."

However, during this chamber they did not take advantage of some of the prominent sensory stimuli elements such as dotted lines that indicate a relationship between a switch and another object such as a door, panel, or cube dispenser. Also, they did not even take a look at the wall displays that provide information regarding what kind of game objects will be awaiting them in the testing course.

Clarity of the goals and rules.

The team indicated that the goals and the rules of the game were very clear to them (Table 19), except in testing course six. However, it was observed at numerous points during the game play that their understanding of the system and procedural rules were not truly right but evolving. For example, in the earlier testing courses Dan was still confused about the system rules around portaling. After placing his portals and teleporting from one side of the room to the other side, which he was looking at earlier, he asked: *"Ok, where are we? What is this over here?"* Later in the game he gained complete understanding of how portals worked and did not display any other confusing regarding this.

Table 19

Reported Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Dan	Amy
Testing Course 1	26	20
Testing Course 2	25	24
Testing Course 3	21	21
Testing Course 4	24	22
Testing Course 5	26	28
Testing Course 6	26	18

Another aspect of the game that the players had to learn the rules about was the ever-changing game objects they were faced with. For instance, when they entered the third testing room they encountered the laser beam and the laser receivers for the first time in the game. Although it did not take too long for them to configure how the procedural rules were dictating them to use the laser beam and the receiver, at first they were a little confused. Initially they tried to activate and shoot laser receivers, or they tried to put a cube on the receivers thinking that it could be another floor button, until Amy realized that they could use the cube to direct the laser beam into the receivers.

> *Dan goes to one of the laser beam switches and tries to activate it. After Amy put the cube on top of the laser beam switch, nothing happens. While Dan is exploring the area he goes under the laser beam and Amy realizes: "This cube*

directs that laser beams." She takes the cube and puts it under the laser beam.

Amy: "Ok let me put this here and I hope we can turn it, although I don't know how."

Along the game through trial-and-error, they learnt other system rules that confined or opened up the new possibilities for their actions in the game:

Amy: "Oh I can't shoot through the glass."

Dan: "Can we get another cube?" Amy: "Probably." After pressing the button to release the cube, the existing cube disintegrates and the new cube drops down.

Dan: "Can we put one more portal on that wall?" Amy: "If we do it right we might be able to get one more portals on it." After trying a few times, they were able to put two portals side by side on one wall.

Dan: "Is there a way we can move this? (The source of the laser beam)" After trying to shoot portals on the laser beam source, nothing happens and he gave up.

Amy: "What happens if you are stepping on that and I get off of this." Dan: "I get crushed." Amy: "Sorry I thought maybe it would launch you."

After coming back Dan tries to put his portals though the glass. Amy: "You got to go around the glass."

As Amy puts down the cube to get ready to shoot a portal the cube falls down the ledge, and through that mistake they realize that she can also jump down without dying.

Although the team did not talk about the end goal of the each testing course very often, it was observed that they both had a common understanding that they need to find a way to open the door to proceed to the next testing course. The repetitive end goal of each testing course was obvious for the experienced game players.

Their learning experience with the procedural and system rules of this game assisted the team with their collaborative problems solving activity. Together they were able to construct a shared understanding of their problem environment, which consist of the system rules, and the actions of the problem space through understanding of the procedural rules. The clarity of the goals helped them understand the problem easier; however, the game mechanics were not always easy even though they were conceptually aware of the problem space and what needs to be done to solve the problem. On the other hand, in testing course six, the team was not very clear what the end goal was since this testing course did not have the same repetitive goal of opening a door to go to the elevators. This was reflected in their gameplay and in their conversations. They mostly executed individual actions during this testing course, and were not constructing a shared understanding of the problem space together as much. Although they were able to identify their initial state, they seemed confused several times about the middle states that they need to be. They found out where they need to portal themselves after a long exploration of the area, since the game design did not provide a lot of clues on where to proceed. After the testing course was over, they both seemed confused and were not sure if that was the end of the testing course. At the end, the clarity of the testing course goal negatively influenced their way of collaborating and constructing the shared understanding of the problems space, but did not stop them from solving the puzzle.

Chamber II (Mass Velocity).

Dan and Amy started to play the second chamber of this game during their first session. They completed first testing course during the first session and the rest of the testing courses during the second session. This chamber introduced new and more challenging tasks and game objects such as flinging action or spring boards. Unlike Dan, Amy was familiar with the act of flinging. However, throughout this chamber, Amy mentioned how she cannot perform or conceptually make sense of the flinging action which indicated that her confidence was low. At the beginning Dan was following Amy's instructions on how to perform a flinging action to gain enough momentum to reach across wide gaps. This caused them to spend too much time in testing course one, as her pervious knowledge of the flinging action was proving itself to become an obstacle in their ways to identify new solutions. Instead of falling into a portal from a ledge, Amy based on her previous experiences, suggested that they should keep falling from one portal to another to gain more momentum before they shoot out of a portal to reach across. Dan accepting her proposal kept performing this action numerous times until by mistake he fall into one portal and shoot out of a portal reaching across. Without realizing that Dan achieved the end goal without falling into portals several time, Amy continued to pursue her strategy. After a long time and numerous tries, she was able to successfully shoot herself out of a portal to reach across using her own strategy. Throughout the other testing courses, the team got into the habit of performing a strategy many times even if it was not working after several tries. Their lack of acknowledgement of the sensory elements changed during the testing courses that they had hard time completing. As the testing courses got more challenging, they started to observe and talk about their game environment more during the process of constructing a shared understanding of the problem. Throughout this chamber it was observed that they were equally contributing to the collaborative problem solving process, and they completed 6 of the 8 testing courses with average time of 16 minutes 26 seconds with testing course five taking the longest time (49 min 51 sec) and testing course two taking the shortest time (2 min 35 sec).

***Collaboration*.**

During this chamber, Dan and Amy demonstrated collaborative actions 72% of the times (Table 20). They equally contributed to the problem solving activity through proposing and discussing their ideas. While the number of demonstrated functional roles indicated a balanced distribution throughout the six testing courses in terms of proposing (50%-50%), modifying (48%-52%), and contesting (46%-54%) an idea, Dan was more active at executing his of own moves without having any conversation about them during this session (79%). It was also observed that when he has an idea on how to solve the puzzle he would not share the details of his plan with his team mates beforehand. Instead he would start with "*I think I know what we have to do*" and then would tell Amy the next action she has to perform, but without telling her what the end goal of this action was. Since they both are experienced gamers, Amy mostly understood what the end goal would be without having a conversation about it as soon as Dan told her what to do. On the other hand, when Amy had an idea she would share her whole plan with him first, and then they would both act on it. In other cases, where they were both stuck at coming up with a solution, they portrayed a richer collaboration through assuming higher number and variety of functional roles. For example during testing course one and testing course four, the team got involved in assuming more functional roles than any other testing courses not only just due to their repetition of implementing the same plan over and over again but also due to the higher number of ideas produced, contested, and modified.

Table 20

Frequency of Functional Roles Assumed During Portal 2 Chamber II

		Testing Course 1		Testing Course 2		Testing Course 3		Testing Course 4		Testing Course 5		Testing Course 6		Dan Total	Amy Total	Total
		Dan	Amy	Dan	Amy	Dan	Amy	Dan	Amy	Dan	Amy	Dan	Amy			
Execution	N	32	11	1	1	4	0	3	0	106	27	24	6	170	45	215
	%	74.42	25.58	50	50	100	0	100	0	79.7	20.3	80	20	79.07	20.93	27.32
Proposal	N	10	8	2	1	3	3	2	1	15	15	2	6	34	34	68
	%	55.56	44.44	66.67	33.33	50	50	66.67	33.33	50	50	25	75	50	50	8.64
Implementation	N	45	118	7	8	12	26	15	26	53	57	13	19	145	254	399
	%	27.61	72.39	46.67	53.33	31.58	68.42	36.59	63.41	48.18	51.82	40.63	59.38	36.34	63.66	50.7
Modification	N	5	9	2	0	1	0	2	1	1	4	2	0	13	14	27
	%	35.71	64.29	100	0	100	0	66.67	33.33	20	80	100	0	48.15	51.85	3.43
Contestation	N	3	3	0	0	0	0	0	1	2	3	1	0	6	7	12
	%	50	50	0	0	0	0	0	100	40	60	100	0	46.15	53.85	1.52
Rejection	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acceptance	N	1	2	1	3	1	0	0	1	5	2	3	1	11	9	20
	%	33.33	66.67	25	75	100	0	0	100	71.43	28.57	75	25	55	45	2.54
Reasoning	N	5	3	0	0	1	0	2	3	1	0	0	0	9	6	15
	%	62.5	37.5	0	0	100	0	40	60	100	0	0	0	60	40	1.91
Testing	N	2	1	0	0	3	1	0	0	11	5	3	0	19	7	26
	%	66.67	33.33	0	0	75	25	0	0	68.75	31.25	100	0	73.08	26.92	3.3
Explanation	N	2	1	0	0	1	0	0	0	1	0	0	0	4	1	5
	%	66.67	33.33	0	0	100	0	0	0	100	0	0	0	80	20	0.64
Total	N	105	155	13	13	26	30	24	33	195	113	48	32	411	376	787
	%	40.38	59.62	50	50	46.43	53.57	42.11	57.89	63.31	36.69	60	40	52.22	47.78	100

Joint problem solving.

Dan and Amy had a distinct way of not speaking of the end goal or the middle states of the problem space for most of times, but still had the shared understanding of them. The experienced gamers did not have to explicitly specify that “this is the door we need to get out” or “this is the ledge we need move forward to” for the testing courses when it was easy for them to figure out what they were supposed to do. However, identifying their initial states and figuring out the possible actions indicated that at most times they were aware of what the middle state would be once they performed an action. Even then, it was sometimes observed that the team conducted strategies and actions without being aware of the consequences, but at the same time having a sense that it would get them one step closer to the solution. In addition, they, especially Dan, generally used vague language to indicate their partner when they had an idea.

Dan: "I think I know what to do." Amy: "Good. Because it hurts my brain"

Dan: "I see what I have to do here."

Dan: "OK. Let’s works this one step at a time."

Dan: "How did we get up to the top for the first time? I think that's the key. Getting to the first level first and then sending one person up. There is got to be a way to obviously get both people over" Amy: "I mean you have to get someone on to the second level in order to get someone at the third level.”

Amy: "Maybe we are over-thinking this…We have to be at this orientation. Somebody at this level and somebody at the top level."

Amy: "I feel like the fact that we can get you launched over to the other side of the force field without losing your portals is important. And maybe we should do that."

Amy: "Because we can both be over there." Dan: "I think the key is to keep on going."

Here we can see, how the two differed in their approach to comprehend problem and create a common understanding of it. Amy was more verbal regarding identifying the initial states, middle states, and possible actions; whereas Dan would only speak about actions and very rarely talk about his understanding of the states within the problem. However, in between two of them they were able to construct the shared understanding of the problem and tackle them successfully. Below presented are some examples of how their language reflects their process of creating a shared understanding of the problem space:

Dan: "We are trying to get up there right? Amy: "Right." (In one of the rare occasions Dan confirms what the end goal is with his partner) *Dan: "Is there a way to launch yourself?"* (Identifying an action) *Amy: "You may want to shoot your blue one as you fall through it."* (Identifying an action) *Amy: "Let me put the red one higher to give you more downwards velocity."* (Identifying a middle state and an action)

Amy: "I found a button. Oh we need one of those baseballs again." (Identifying initial states)… *Amy: "There is a draw from there (following the dotted blue lines) so there must be a button for it up there.* (Identifying a middle state) *How do we* *get up there? We get up there by launching from over here* (Identifying an action)*." Dan: "I got to figure out how to get up where the other switch is."* (Trying to identify an action) … *Dan: "I am going to put the continuous portals right here."* (Identifying a middle state and an action) *Amy: "There we have another continuous loop."* (Identifying an initial state) *Dan: "I think I see what is going on here. We got to set up our portals first.* (Identifying a middle state) *So I am going to be launched* (Identifying an action)*. (He is looking for a wall that he will be launched from). I need to get over there* (Identifying a middle state)*. (Looking across where the button is)" Amy: "Yeah." Dan: "Where do I get launched from? Ah there is one up here. So, can you put a portal up here* (Identifying an action and middle state)*?" Dan: "Ok here it is."* (Identifying a middle state) *(He sees the forever falling portals.) Amy comes over and puts the portals immediately and asks: "And then what?" Dan: "Then you put the red one on one of those."* (Identifying a middle state and action) *Amy: "One of these?" Dan: "Yeah" Amy: "Do you think you will get up high enough." Dan: "Yeah definitely." Amy: "We need a ball* (Identifying a middle state)*. And there is a ball droppy thing* (Identifying a middle state)*."*

In these two conversation examples we can see Dan and Amy collaboratively identifying problem states, actions, and some associations between actions and states. Their language reflects how both of them contributed to the problem solving activity and developed a joint problem space.

Influence of the game elements on collaborative problem solving.

Challenge.

The team experienced the most difficulty during testing course five of this chamber, as also can be seen from their rating of their perception of the challenge levels reported in Table 22. Even though the reported challenge levels for the testing course one was at a medium level, it was observed that the team had some difficulties during testing course one as well.

Table 21

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Testing Course 1	Dan	7	32	10	45	5	3	0	1	5	2	2
	Amy	9	11	8	118	9	3	0	2	3	1	1
Testing Course 2	Dan	4	1	2	7	2	0	0	1	0	0	0
	Amy	3	1	1	8	0	0	0	3	0	0	0
Testing Course 3	Dan	5	4	3	12	1	0	0	1	1	3	1
	Amy	6	0	3	26	0	0	0	0	0	1	0
Testing Course 4	Dan	7	3	2	15	2	0	0	0	2	0	0
	Amy	6	0	1	26	1	1	0	1	3	0	0
Testing Course 5	Dan	13	106	15	53	1	2	0	5	1	11	1
	Amy	16	27	15	57	4	3	0	2	0	5	0
Testing Course 6	Dan	6	24	2	13	2	1	0	3	0	3	0
	Amy	10	6	6	19	0	0	0	1	0	0	0

In testing course one the difficulty the team had was more so due to the game mechanics than the difficulty of the problem, whereas in testing course five the challenge level was high because the complexity of the problem was increased. These two challenging activities caused by two different types of occurrences, affected their assumed functional roles diverse ways. In testing course one, Amy was confident she knew what has to be done and proposed ideas mainly and Dan followed her lead. However, she was not confident that she could actually be able to perform the action that she thought that needs to be done. In testing course five, they were both having trouble coming with ideas that will help them solve the puzzle due to its complexity. It was observed that they both equally contributed to the idea generation and implementation. Since it was really challenging for both of them, they had to work together more in this testing course than in any other testing courses. When the challenge level was low, one of them would easily come up with a solution without as much help needed from a partner. Therefore the increased level of challenge due to increased complexity of the problem, although frustrating for them at certain points, was a catalyst that helped promote more team work during this chamber. It is also important to note that during testing course five, Amy indicated that if they were playing this at home she would have consulted to internet walkthroughs by now to help them solve the puzzle quicker. This unfortunately might indicate that under an uncontrolled setting, the increased challenge levels might push players to other means of finding solutions rather than collaboratively solving the problem.

The team faced couple of challenging testing courses during this chamber. As mentioned earlier, while testing course one was challenging in terms of its game mechanics, testing course five was challenging in terms of its problem complexity. These two outstanding instances shed a light to our understanding of how they constructed their shared understanding of the problem under different circumstances.

During the first section of the testing course one, Amy gave up on performing the flinging action after she explained to Dan how to do it. She mentioned several times that she was not comfortable with this action and that she did not understand the concept. This unfortunately stalled their collaborative problem solving process slightly. As Amy was not comfortable with the action that she thought needed to be taken, she convinced Dan that it was a difficult move to perform. Therefore, they assumed that their numerous failing attempts were due to the difficulty of the game mechanics, and not due to the fact that they were trying to implement a very hard solution to a problem which had a very easy solution. Unfortunately, this anticipated difficulty in the game mechanics hindered their problem solving process.

Testing course five was a different kind of a challenge that they had to face which almost brought them close to giving up. After they exhausted various ideas and repeatedly performed some of their constructed strategies, they came up with a solution by almost mere chance. Like any other testing courses, this testing course required series of certain forms of action to be taken to get the two players into strategic locations before they can perform a final action to complete the puzzle. The team was very much aware that they were positioned in right locations and they were very close to solving this puzzle, but they were not able to figure out the final action needs to be taken to bring them both to the exit door. The reason why this final action was challenging to identify was because it was never used in previous sections of the game before and if the portaling and teleporting concept was strange enough to comprehend this final action was even harder. The players had to teleport back to the spring board using their previously placed portals to gain enough momentum to shoot back from the same portal which they teleported in. This never-before-encountered complex concept combined with the fact that they kept switching their portals without looking into their previously placed portal – which took out the chance to discover this action – made this level very challenging for the team. However, this kind of challenge caused by the complex problem faced encouraged them to communicate more effectively and scrutinize their problem space more in detail.

During the other testing courses that have low to medium challenge levels, the team still performed well solving the puzzles, however, it was observed that a common understanding of the problem space was not always successfully built up. There were various occasions where Dan would figure out how to solve the problem and ask Amy to perform certain actions without explaining his idea as a whole. Sometimes Amy would understand what his plan is about half way through, and other times she would perform an action without understanding and also without questioning him.

> *As soon as he sees the forever falling portals, Dan: "Ok here it is." Amy comes over and puts the portals immediately and asks: "And then what?" Dan: "Then you put the red one on one of those." Amy: "One of these?" Dan: "Yeah" Amy: "Do you think you will get up high enough." Dan: "Yeah definitely."*

This example shows how Amy performed an action (shooting portals) without understanding the next steps of the plan. However, she questioned him after taking an action. Dan told her the next action she needed to take (shoot another portal in a second location). Amy understood what his plan was as soon as he pointed out the second location for the portaling action.

Sensory stimuli elements.

Although the team ignored the static sensory elements such as wall displays and signs for the most of this chamber, they acknowledged and utilized the other types of sensory elements during their collaborative problem solving activities. One of these directive sensory elements was the dotted lines that changed colors based on player interaction with buttons and doors. Until the first testing course of this chamber, there was no mention of dotted lines in their conversations even though they encountered them earlier in the game. Amy was the first and only one to take the blue dots into account while proposing or contemplating on an idea:

Amy: "There is a draw from there (following the dotted blue lines) so there must be a button for it up there. How do we get up there? We get up there by launching from over here."

Dan: "I got mine positioned all the way up there." Amy: "I don't think we need to be up there yet. I think we need to get up here first. Because this seems to be where the blue line goes which makes me think that there is a button right here that is going to release the baseball thing." Dan: "OK."

Amy: "There is no little dotted lines which usually leads you to a button."

They also took help from various auditory sensory elements during this chamber. Mainly the ticking sound indicated them about the limited time they had and helped them propose ideas.

Dan: "What is that button do?" Amy presses the button and ticking noise is heard. Amy: "It is timed." Dan: "Ok I know what we have to do." Amy: "OK." After Dan press the second button, Amy: "Oh I am going to have to do it too."

After pressing the first tower button, ticking noise is heard. Amy: "Ah-ha now we have to do the other one." Dan: "We ran out of time though. We got to do it in succession I guess."

During more challenging testing courses, the team paid more attention to their surroundings and relied on more sensory elements given by the game. For example, in testing course five when the team was struggling to come up with a right solution, they started to examine the every little detail of information provided to them in the room through sensory elements. Although there were times of confusion that were a result of a sensory element encountered, these moments still promoted conversations and, at times, collaboration.

Amy sees the target on the side wall and tries to shoot a portal on it: "Aaah. No. Why do we have a target on here?"

Dan: "What is that white light? Is that anything to?" Amy: "It is just an office."

Amy: "It just feels like that should be an elevator or something, because why does it have an up arrow on it? ... It is just water. Definitely, no elevator over there. Maybe it is just telling us that is the way to go, but why is it under there?"

Overall, the functional roles observed during their collaborations were slightly influenced by the sensory elements in a beneficial way. As can be seen in the table below, some sensory elements promoted conversations and actions, whereas some went unnoticed or unmentioned. The Table 21below showcases the observed functional roles as an immediate result of an encounter with a sensory stimuli element.

Table 22

Sensory Stimuli Events in Chamber II

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
Visual	Directive	Dotted lines	B-P B-I	Amy: "There is a draw from there (following the dotted blue lines) so there must be a button for it up there. How do we get up there? We get up there by launching from over here."
		Dotted lines	B-C B-P	Dan: "I got mine positioned all the way up there." Amy: "I don't think we need to be up there yet. I think we need to get up here first. Because this seems to be where the blue line goes which makes me think that there is a button right here that is going to release the baseball thing." Dan: "OK."
		Dotted lines	B-S A-E	Amy: "There is no little dotted lines which usually leads you to a button."
	Informative	Bulls-eye on the wall	B-E	Amy sees the target on the side wall and tries to shoot a portal on it: "Ah. No. Why do we have a target on here?"
		Arrow pointing up	B-P B-C	Amy: "It just feels like that should be an elevator or something, because why does it have an up arrow on it? ... It is just water. Definitely, no elevator over there. Maybe it is just telling us that is the way to go, but why is it under there?"
	Decorative	Office with lights on	B-E	Dan: "What is that white light? Is that anything to?" Amy: "It is just an office."
Auditory	Informative	Ticking noise	A-P B-A A-M B-I	Dan: "What does that button do?" Amy presses the button and ticking noise is heard. Amy: "It is timed." Dan: "Ok I know what we have to do." Amy: "OK." After Dan press the second button, Amy: "Oh I am going to have to do it too."
		Ticking noise	B-P A-A A-I	After pressing the first tower button, ticking noise is heard. Amy: "Ah-ha now we have to do the other one." Dan: "We ran out of time though. We got to do it in succession I guess."

Notes. [a]A: Dan B:Amy / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

Although Dan and Amy did not always explicitly talk about the sensory stimuli elements while they were constructing a shared understanding of the problem, they took most of the subtle hints into account. The auditory sensory stimuli elements were almost always recognized and used during the collaborative problem solving process, on the other hand, the visual sensory elements were acknowledged only on certain occasions.

In testing course one, for a change, Amy examined the room and explained the role of the blue dotted lines while she proposed her idea: *"There is a draw (dotted blue* *lines) from there so there must be a button for it up there. How do we get up there? We get up there by launching from over here."*

The team made extensive use of auditory sensory elements during their planning stage. In some of the testing courses the team encountered a timed event that required them to complete an action before the ticking noise disappears – in approximately 5 seconds.

> *Amy presses a button and ticking noise is heard. Amy: "It is timed." Dan: "Ok I know what we have to do." Amy: "OK." After Dan press the second button, Amy: "Oh I am going to have to do it too."*
>
> *Amy: "Ahha now we have to do the other one." Dan: "We ran out of time though. We got to do it in succession I guess." Amy: "How can we possibly do it that fast?" After looking around Dan comes up with a solution. Dan: "Ok I think I know. Once I go up you take the yellow portal and put it on this one. My momentum should carry me up to this one too."*

However, the sensory stimuli elements such as color changing dots or ticking noises are alone not enough for them to be able to solve the puzzle. There are other subtle sensory elements that complete the piece of the puzzle for them throughout the chamber. For example, the placement of portals – two facing each other – means that they will have to use it to set up portals to create a forever falling cycle to gain momentum, or angled portals that are used to be shoot out from after enough momentum is gained, or the shape of switch box on the ground which tells them whether to step on or place a ball/cube to activate the object associated with it. During their gameplay it was observed that the team acknowledged almost all of these subtle sensory stimuli elements into account and successfully created a shared understanding of the problem that they were facing.

Clarity of rules and goals.

Although the team indicated that the goals and the rules of the game were clearly presented and easy to comprehend (Table 23), during this chamber it was observed that some of the operational and procedural rules were still not clear to Dan and Amy. Overall, their general understanding of the procedural rules helped them during their collaborative problem solving process. In occasion they seemed not sure and confused about certain procedural rules – especially regarding flinging action:

> *Dan: "Is there a way to launch yourself?" Amy: "Yeah there is. This is what I can't do. This is the one mechanic I was describing that does not make any sense to me and I don't understand how to do it. But yeah you fall into your portal and then loop through it and it will shoot you across?" Dan: "That is the one (portalable wall) right here right?*
>
> *They do not realize how he actually got himself launched across. Dan thought he was following Amy's plan to shoot a portal after he jumps into the yellow portal but instead by mistake he shoots his portal early and places Amy's yellow portal with his Light blue portal which allows him to gain enough velocity to shoot him out of his dark blue portal. They have no idea that this is how he got across. After placing her portals for Dan to start the forever falling cycle, she walks through a force field and it erases her portals. Dan surprised: "Where did it go?" Amy: "Oh I walk through that ahha, hmmm. When I went through there (blue force field) my portals went away."*

This discussion illustrates Dan and Amy's misconceptions and confusions about the game rules.

Table 23

Reported Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Dan	Amy
Testing Course 1	24	30
Testing Course 2	27	30
Testing Course 3	27	27
Testing Course 4	25	30
Testing Course 5	25	28
Testing Course 6	26	30

There were also occasions where their understanding of the operational rules as individuals or as a team was not firm. When one of them was not sure how the system works, and the other one was knowledgeable, they helped each other to understand the rule. When the team was not sure about how the game environment allows or constrains their movements, they mainly pursued the action in their mind to see the consequences of it. This unclarity lead them to share their understanding of the problem space with one another, or test their ideas to shape their shared understanding of the problem space together.

Dan: "If I come down will I die?"

While Amy was trying to shoot a portal through the blue force field, Dan tells her to back up a little bit.

Dan: "Can I walk through there with the ball?" He walks and the ball disintegrates.

Dan: "Is it portable?"

Amy: "If we go through that do our portals disappear in both directions or only behind you?" She walks through the force field: "Ok both directions. I thought the one behind would maybe stay."

The repetitive goals of the game did not require as much explanation or presentation for these experienced gamers, as they both had a grasp of what they had to do even without knowing the end result of their actions. As a team they knew they had to move forward to the next opening they see in the testing course, and they were able to identify some of the key middle states with the help of the subtle sensory elements. As mentioned earlier, at certain occasions it was not clearly observed that they had a common understanding of the problem when they started to solve the puzzle. This might be because that the clear, obvious, and repetitive goals did not encourage them well enough to talk about the goals. However, after they started taking action in the game their conversations helped them share their understanding of the goals and develop a common understanding.

Dan: "Hold on keep that. Put yours (portal) on the other side over there." Amy: "Other side?" Dan: "Other side of where that red one (portal) is. Put that red one on the other side." Amy: "Can I get to the other side?" Dan: "Yes, you can turn around and you can see it." Amy: "Oh I see."

In this example, we see that Dan was aware of what the end goal (Go to the other side of the wall) and problem states (needed portals on both sides) were. However, because Dan did not share his understanding of the end goal and problem states before he asked her to take an action, Amy seemed confused. Amy was not sure about the end goal (being on the other side), and how she can get there (through portals) until Dan explained. At the end of this conversation they were able to come to common understanding and therefore complete the part of the puzzle.

Within Case 3 - Group 3 (Mike and Dale) Playing Portal 2

As soon as the game started loading Mike asked Dale if he knew anything about the game, and explained the premise of the game to him when he said he did not know anything about it.

> *Mike: "So how familiar or not familiar with portal?" Dale: "Pretty not familiar." Mike: "So the concept is puzzles and you have a magic gun that shoots a portal and there is interesting physics to go along with that like conserve your vertical velocity if you change to a horizontal plane. Umm Co-op, I think we can only create one portal each." Dale: "OK" Mike: "Which means we have to work together to create the entrance and the exit." Dale: "OK" Mike: "Of course you can also do fun things like create two portals directly below and above each other so you can fall forever." Dale: "Is that a good thing?" Mike: "You don't take fall damage. So during the co-op usually computer taunts you."*

This conversation was a fist sign of what is expected to be a case of unbalanced team dynamics. The team with Mike’s lead completed all the testing courses during their first research session. Mike obviously had previous Portal gaming experience, and Dale was not very familiar with the game or with the gaming system. During the tutorial session Dale quickly adjusted to the game controllers and environment, and started to be little more independent. However, it was observed that Mike was still in charge of the team and the problem solving activity throughout the gameplay. Even though they were acquaintances, more specifically classmates, they portrayed a very unfriendly social connection, with very little or no conversation outside of the gameplay during the research session. This awkward social dynamics also played an interesting role in their collaborative problem solving. Mike tended to speak very soft in a way that made him look like he was just thinking out loud instead of having a conversation with his teammate. Also in some cases, Mike was not able to communicate well with his partner in conveying his ideas. Therefore, sometimes Dale had to initiate conversations to clarify what Mike was actually thinking in his mind. They also displayed a different type of humor where trying to harass or kill the teammate in the game environment was acceptable. This team played *Portal 2* in their first session and completed tutorial and chamber one in approximately two hours.

Tutorial chamber.

Although Dale's inexperience in playing video games was evident in the initial stages of his gameplay in the tutorial session, he was able to get used to the game controls quickly and was able to learn the premise of the game easily. During the tutorial level, Mike was in charge and led the team towards the solution all of the time with some occasional help from Dale. His gameplay expertise and familiarity with the Portal game series resulted with a one-sided group dynamics, with Mike was solving the puzzles himself and Dale following his instructions. While observing their gameplay, it was noticed that Mike was speaking very softly making it difficult to understand what he was saying. However, when the session videos were analyzed it was seen that Mike in fact was making jokes and explaining to his partner the necessary moves and steps of the game. In addition to verbal explanations, in some rooms Mike excessively used game tools such as pinging that was designed to indicate a partner where to pay attention or place a portal when communication is unavailable. He used this tool instead of communicating when he realized Dale did not know what he needed to do. For example, in room five, Dale was confused and did not realize that he had to place a cube into a floor switch. He was just looking around his side of the room. After Mike placed his cube into his floor switch that opened Dale’s door, instead of explaining to Dale what he should do, Mike started pinging the cube. This pinging action lighted up the cube and displayed an icon on Dale’s screen. This helped Dale realize that he had to interact with the cube. As soon as he picked up the cube, Mike pinged the floor switch without saying anything to indicate Dale that he needed to bring the cube to the floor switch. Using the ping tool without any conversation was rather a peculiar action that was not observed with the rest of the teams. When other teams utilized the ping tool they were talking to each other and using the tool as a supplemental element to point out a specific location or game object.

Collaboration and joint problem space.

Throughout the first three rooms of the tutorial, there were hardly any signs of collaboration. Dale was very disoriented and was trying to follow Mike’s instructions to get to proceed in the game environment. In room four the nature of the conversation showed signs of changing from Mike giving straight instructions (e.g. “*Turn around and shoot a portal on the angled surface*”), to Mike trying to suggest solutions where Dale had his input as well.

> *Mike: "Where are you? Where did you go?" Dale: "What's that?" Mike: "Where are you?" Dale: "I walk through a force field after looking through at you and now it seems that I am in a hole." Mike: "Can you go back?" Dale: "I think you might have shut the door that I went through." Mike: "Here you are." Mike: "You can go through if you go upstairs." Dale tries and can't go up. Dale: "Yeah that's*

what I.." Mike: "Oh that is where the puzzle part comes in. If you go back up to stairs. You got one there. Hmm."

In room five, as mentioned before, the conversation between the partners reduced dramatically and the only way Mike provided some sort of guidance to Dale was through pinging the game objects to get Dale's attention focused. In room six the unbalanced group dynamics continued and Mike came up with a solution himself and explained to Dale what he had to do so that they could complete the puzzle. During this room Dale started to ask Mike directly about what he was doing. His inquiry, prompted Mike to share his thoughts.

Dale: "So what do you try to manipulate with that block over there?" Mike: "That's what I don't know yet." Mike: "You don't have anything else on your side do you?" Mike: "Oh, I see Ok. I cannot take this block to the other side. But I need to get over there."

Here, we see Mike and Dale started to build a common understanding of the problem because Mike started to verbalize his understanding of the problem space. This was only possible because Dale directly asked his partner to share his thoughts. However, Mike's style of sharing his thoughts seemed like he was just thinking out-loud rather than he was talking to Dale.

Mike: "Now it is your problem." Dale: "Oh Thank you...Do I have some idea where I want to bring this block?" Mike pings the floor switch and tells him: "Here" Mike: "No, but you can pass it to me. Hold on." Dale: "Yeah."

After Mike figured out a way to passing the cube to his partner, he jokingly indicated that Dale needed to figure out the rest of the problem. Although in this conversation was in a joking manner, it still indicated Mike's small commitment to the collaborative problem solving process. When Dale asked him about where to take the cube, it made it obvious that he was not paying attention to Mike's think-out-loud process and Mike continued to instruct him and collaborated with him to solve the rest of the puzzle.

In the last room of the tutorial, Dale also started sharing his ideas to help come up with a solution, although not in a confident way.

> *Dale: "I can theoretically make a portal over on your side, but I am not sure if that helps anything." (Dale shoots a portal anyways) Mike: "I can't get a block across this border (force field) and I need a block to make this permanent. What do you have up ahead?" Dale: "There is a button on your side." Mike: "But you can't go. I can."*

After Mike realized that they needed Dale to create the portals to solve the puzzle, he asked Dale to shoot portals for him. This room was the first room where they seemed to work as a team the best, and constructed a common understanding of the problem that they were facing. They examined the room together and identified middle states that they need to achieve. Although it was not a best example of constructing a shared understanding of the problem, it was still an improvement over their collaborative process in the other rooms.

Table 24

Frequency of Functional Roles Assumed During Portal 2 Tutorial Chamber

Functional Role	Mike		Dale		Total	
	N	%	N	%	N	%
Execution	72	45.28	87	54.72	159	74.65
Implementation	8	40.00	12	60.00	20	9.39
Proposal	9	81.82	2	18.18	11	5.16
Contestation	0	0.00	0	0.00	0	0.00
Rejection	0	0.00	0	0.00	0	0.00
Acceptance	1	100.00	0	0.00	1	0.47
Modification	1	100.00	0	0.00	1	0.47
Reasoning	0	0.00	1	100.00	1	0.47
Testing	0	0.00	0	0.00	0	0.00
Explanation	20	0.00	0	0.00	20	9.39
Total	111	52.11	102	47.89	213	100.00

As represented in Table 24, during the tutorial level, Mike and Dale mostly executed individual moves (84% of all functional roles) and took very few collaborative roles (16%). As can be seen from the distribution of their functional roles, Dale executed (55%) relatively more individual moves than Mike (42%) due to the fact that he needed to try a lot more moves to get to the right solution. In the very small amount of collaborative functional roles observed, Mike proposed more ideas (82%), and Dale implemented more ideas (60%) as he was following Mike's proposals most of the time.

Influence of game design elements on collaborative problem solving.

Challenge.

Although both team members equally rated the challenge level of this section of the game as six out of 20, it was observed that Dale had more difficulty maneuvering around the game world at the beginning of the tutorial. However, as he got used to the game controls and the concept of the game, he contributed more to the collaborative problem solving process instead of just relying on Mike. Throughout the level, the testing courses presented progressively increasing level of challenge, which induced more conversations about the problem between the teammates. Although not a thorough collaboration, the increased challenge level along with Dale's improved gameplay skills helped the team construct a stronger shared understanding of the problem.

Sensory stimuli elements.

Although tutorial level utilizes more sensory stimuli elements as a feedback and feedfront mechanisms, Mike and Dale paid attention to a very few of these. Mike was more observant and knowledgeable about the function of most of the sensory elements including floor signs and blue dotted lines. However, he only spoke of them in two occasions:

Dale: "So what does this pressure point opens? The door your side?" Mike: "Usually the arrows (dotted lines) always point towards the door it opens."

While looking at signs on the floor, Mike: "These usually helpful signs that tell you what to do, not to do."

In this instance, Mike provides Dale with more information about the sensory elements when specifically asked by Dale. This shows Mike is knowledgeable about these elements yet did not tend to share information about them without being asked.

Dale was still learning how to play the game and what every sensory element meant. Therefore, his gameplay showed a little or no understanding of how to utilize the sensory elements. When he saw a sign on the floor he inspected it, and tried to shoot portals on it. He did not pay too much attention to verbal feedback given by Glados at the beginning of the tutorial about not being able to shoot portals on dark surfaces.

During this level of the game, it was really difficult to observe any relationship between their minimal level of collaboration and the sensory stimuli elements. However, those verbal and visual sensory elements might have influenced how they individually shaped their own understanding of the problem space. Especially, the subtle clues such as shapes and colors of object was observed to help Mike to understand what needs to be done to solve the problem.

Clarity of goals and rules.

The team, mostly Dale, learned the operational and procedural rules of the game along the tutorial level. They learned about some of the system rules that confined their movement in the game environment through trial-and-error:

After trying to shoot a portal through glass, Dale: "So you can't shoot through some things."

Dale figured out that he can only make one portal at a time with each control button Dale: "Oh alright, so what I did was I got rid of one of them by making a portal, fair enough."

After Mike tried to walk through a force field with a cube in his hand, the cube disintegrates. Mike: "Oh I see Ok. I cannot take this block to the other side. But I need to get over there."

Mike: "It is not big enough for me to put a portal."

Here we see the team spoke about the system rules. This helped the team develop a shared understanding of the problem space in terms of what kind of actions are available or not available. Dale learned and mastered the procedural rules related to the portaling concept during the first four rooms in this level with Mike's help. They also helped each other understand some of the other procedural rules that are essential to identifying the middle states and actions through conversing about them:

Mike: "I think you want to walk towards the glowing door." (Middle State)

Dale: "So what does this pressure point opens? The door your side?" Mike: "Usually the arrows always point towards the door it opens." (Operator)

Mike:" What does this button do?" (Operator)

In accordance with the observations, their reported ratings of clarity of the goals and the rules of this section indicated that Mike (rated 22 out of 30) had a better understanding of them compare to Dale (rated 15 out of 30). The difference in their understanding of the goals and the rules possibly was one of the causes of the minimal collaboration during problem solving process. At the same time, the difference in their understanding of the goals and rules might also be a result of minimal collaboration.

Chamber I (Team Building).

Mike and Dale showcased unbalanced team dynamics during this chamber. In most cases, it was apparent that Dale did not have a clear understanding of the problem, and he just followed Mike’s instructions to complete his part of the problem. In general, their problem solving consisted of individualistic efforts rather than collaboration. Throughout the gameplay, Mike was the main problem solver and proposer of ideas, and Dale was the follower. In some cases, Mike did not even explain the big picture to his partner after he figured out how to solve the problem himself, but just asked him to simply perform certain actions without stating the consequences of them. This occasionally resulted with Dale requesting clarification or even approval before he performed any actions. Their communication was not healthy. Mike continued to speak in a very soft manner, where Dale had to ask him to repeat himself various times. The team had a different style of humor where they enjoyed shooting or troubling each other during the gameplay. For example, in one of the rooms Dale was in control of the elevator that crushed Mike several times. After they complete the task, Mike directed laser light on Dale on purpose hoping that he would explode in a joking way. The two-male team, hence, showcased some differences in their social dynamics during their video game play activity. The team completed all of the testing courses with an average time of 6 minutes 18 seconds with testing course three taking the longest time (9 min 11 Sec) and testing course one taking the shortest time (1 min 51 Sec).

Collaboration.

As mentioned above, this group did not display a healthy collaboration, and mostly relied on Mike's problem solving skills to get through the testing courses. At the beginning of some of the testing courses, Mike would start exploring the room and contrive a solution before Dale could even pick up his controller and get involved in the gameplay.

> *After looking around for a few seconds, Mike: "Ok I think I figured out what we need to do." Meanwhile Dale is still filling out the questionnaire and not engaged in the gameplay yet. Mike continues: "We need to redirect the laser through these (receptors)." Dale finally comes into the room after completing the questionnaire. Mike: "So I can create one portal here." Mike: "So I need a portal there, so I can get to the second thing." Dale: "Yeap." Mike: "So I need one (portal) on the other side." Dale: "So where is the laser trying to hit?" Mike: "This thing over there (He comes over to show him and pings the receptor)" Mike: "Create one (portal)*

behind you." After looking around all confused, Dale: "So you are saying I should create another one like yours?" Dale is confused and cannot seem to identify what he needs to do, he asks Mike: "I am sorry, ping that one more time."

The conversation and gameplay that took place in testing course three presents an example of how Mike did not wait for Dale to solve any problems. While Dale was still filling out the research questionnaire for the previous room, Mike started exploring the testing course and came up with a solution. When Dale started playing, Mike asked him to perform some actions without explaining the complete solution in his mind which then resulted with Dale to ask some clarification.

Throughout the other testing courses, it was apparent that Dale required more clarification as Mike did not communicate his proposed ideas in detail with Dale. Dale also asked Mike to show him what to do through pinging. This might have been accepted as a more useful communication tool by Dale after realizing Mike's style of communication. Also this could be a more convenient way for Dale to understand what game object he needed to interact with since their understanding of the problem space was not shared. Instead of labeling the game objects with something (e.g. crusher, laser thingy, etc.) during their conversations they mostly preferred using a vague language such as "you need to hit it over here" "move these around" "laser needs to go up there." Therefore, using the pinging tool as a supplement to simply communicating with vague language helped them throughout the gameplay.

The unbalanced communication between the teammates can also be seen in the Table 25 that showcases the frequency of functional roles they assumed through this chamber. While Mike proposed most of the ideas (91%) and executed more moves

(70%), Dale (47%) and Mike (53%) implemented almost equal amounts of ideas. Even though overall the team displayed joint decision making functional roles 61% of the times, the quality of the togetherness of the decision making was questionable due to the reasons stated above.

Table 25

Frequency of Functional Roles Assumed During Portal 2 Chamber I

		Testing Course 1		Testing Course 2		Testing Course 3		Testing Course 4		Testing Course 5		Testing Course 6		Mike Total	Dale Total	Total
		Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale			
Execution	N	10	12	11	6	12	4	10	6	8	2	32	6	83	36	119
	%	45.45	54.55	64.71	35.29	75	25	62.5	37.5	80	20	84.21	15.79	69.75	30.25	33.9
Proposal	N	4	0	8	1	12	0	7	1	5	1	2	1	38	4	42
	%	100	0	88.89	11.11	100	0	87.5	12.5	83.33	16.67	66.67	33.33	90.48	9.52	11.97
Implementation	N	5	5	15	11	13	10	15	16	13	14	12	9	73	65	138
	%	50	50	57.69	42.31	56.52	43.48	48.39	51.61	48.15	51.85	57.14	42.86	52.9	47.1	39.32
Modification	N	0	0	0	0	1	0	0	0	0	0	3	1	4	1	5
	%	0	0	0	0	100	0	0	0	0	0	75	25	80	20	1.42
Contestation	N	0	0	1	2	2	2	0	0	1	0	0	1	4	5	9
	%	0	0	33.33	66.67	50	50	0	0	100	0	0	100	44.44	55.56	2.56
Rejection	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acceptance	N	0	1	2	0	1	2	0	0	0	1	2	1	5	5	10
	%	0	100	100	0	33.33	66.67	0	0	0	100	66.67	33.33	50	50	2.85
Reasoning	N	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1
	%	0	0	100	0	0	0	0	0	0	0	0	0	100	0	0.28
Testing	N	0	1	1	1	3	0	1	0	0	1	0	0	5	3	8
	%	0	100	50	50	100	0	100	0	0	100	0	0	62.5	37.5	2.28
Explanation	N	0	0	1	0	7	0	5	0	3	0	3	0	19	0	19
	%	0	0	100	0	100	0	100	0	100	0	100	0	100	0	5.41
Total	N	19	19	40	21	51	18	38	23	30	19	54	19	232	119	351
	%	50	50	65.57	34.43	73.91	26.09	62.3	37.7	61.22	38.78	73.97	26.03	66.1	33.9	100

Joint problem space.

Mike and Dale were very ineffective in creating a common understanding of the problem space. As mentioned before, Mike was successful at solving the problems with little or no intellectual help from Dale. Their conversations during the gameplay often followed a pattern of Mike coming up with a solution himself and asking Dale to perform necessary actions that will successfully get them closer to the end goal. A typical example of their conversation that reflects the ineffective joint problem solving effort is presented below:

> *Mike: "Ok One of us has to...(then stops)" Dale: "Sorry one of us needs to...?" Mike: "I don't know I am still figuring this out." Dale: "OK."*
>
> *Mike: "Someone has to go through."* (Identifying possible action and problem state) *As Dale is going through the first door, Mike: "Go through. Stay on the weight."*
>
> *Mike: "Do you have a portal out here (in room 1)? I need a portal out here so I can get in (to room two). I think I want to get in."* (Identifying possible actions, problem states, and associations) *Dale: "OK" After stepping on the floor button Mike: "What does that open? That opens the same one."* (Identifying a problem state)*Dale: "Yup." Mike: "Did that open a second door anywhere?" Dale goes into the first room to explore if that opened any other doors. Mike: "What is that one open?" Dale steps on it and days: "I am not sure." Mike examines the dotted lines coming out of the floor button he is on towards the first door and says: "This opens that one (first door)."* (Identifying a problem state) *And then moves towards the second door to see if it is opened… Mike: "I think I still have an orange (portal)… No I don't. Coming back, don't move."* (Identifying a problem state)

Dale: "So now theoretically, once you are back there (in third room), I can enter in through that portal?" Mike: "Yeah you should be able to." (Re-stating actions and problem states)

In this example, we can see at the beginning of the conversation that Mike was thinking out-loud. He did this in a very soft-spoken manner. When Dale interrupted him to understand what he was saying, Mike simply told Dale that he was still thinking about it. During the rest of the conversation, Mike simply told Dale what to do in a commending manner (Go through. Stay on the weight. Don't move.) At the end Dale figured out what Mike was trying to accomplish, however he still asked his partner to clarify what his plan was.

The team (mostly Mike) was able to identify the middle states and actions to solve the problem, but they never had talked about the end goals. Even though he never mentioned it, it was observed that Mike knew that his team had to proceed towards the other testing courses. The goal of reaching the exit door in each testing course might have been too unimportant or too obvious to even say something about it. However, the same cannot be assumed for Dale for all the times. For example, in the first section of the room three, he was confused about where to proceed after the team successfully opened the exit door. Here are some of the examples of the middle states and possible actions that the team talked about during constructing their joint problem space:

Mike: "What does that button do?" After pressing the button again Dale says: "Opens that door over there I guess for momentarily." (Identifying an action and a middle state)

Mike: "Someone needs to run through it quick." (Identifying an action)

Mike: "So I need one (portal) on the other side." (Identifying a middle state) *Dale: "So where is the laser trying to hit?"* (Trying to identify a middle state) *Mike: "This thing over there (He comes over to show him)"*(Identifying a middle state)

Mike: "Now what. Oh we need two. (Identifying a middle state) *Need to hit the laser over here (second receptor) too."* (Identifying an action) *Dale: "So we need portals again?"* (Identifying an action)

Mike: "Someone needs to go, I will go.(identifying a middle state) *And someone needs to stay* (identifying a middle state) *and move those around* .(identifying an action)*" Dale: "Because theoretically, you are going to be getting a box* (identifying a middle state), *to then use the laser with* (identifying a middle state)*." Mike: "Yeah."*

Through their conversations during this chamber, it was observed that the team was able to create a diminutive amount of common understanding of the problem space, even if they were not very effective in collaboration and joint problem solving. Mike's ineffective conversational style played a big role in how they, as a team, rarely constructed a common understanding of the problem. In many cases Dale seemed that he did not comprehend the problem space or required some clarification to understand what was going on in his partner's mind. Dale also relied on his partner to show him where to put portals or which objects to activate through pinging the exact locations.

Influence of game design elements on collaborative problem solving.

Challenge.

The participants' perceived level of challenge of each testing course for this chamber along with the frequency of their functional roles is reported in Table 26.

Table 26

Frequency of Functional Roles and Reported Challenge Levels

		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
			Functional Roles									
Testing Course 1	Mike	3	10	4	5	0	0	0	0	0	0	0
	Dale	2	12	0	5	0	0	0	1	0	1	0
Testing Course 2	Mike	5	11	8	15	0	1	0	2	1	1	1
	Dale	3	6	1	11	0	2	0	0	0	1	0
Testing Course 3	Mike	5	12	12	13	1	2	0	1	0	3	7
	Dale	3	4	0	10	0	2	0	2	0	0	0
Testing Course 4	Mike	8	10	7	15	0	0	0	0	0	1	5
	Dale	6	6	1	16	0	0	0	0	0	0	0
Testing Course 5	Mike	7	8	5	13	0	1	0	0	0	0	3
	Dale	8	2	1	14	0	0	0	1	0	1	0
Testing Course 6	Mike	9	32	2	12	3	0	0	2	0	0	3
	Dale	11	6	1	9	1	1	0	1	0	0	0

According to the challenge ratings, the last three testing courses were more difficult for Mike and Dale. The Table 26 indicates that the team displayed more variety of functional roles when the gameplay was easier (testing course two and three) and when it was very hard (testing course six). Similar to their scorings, my observations also indicated that the team had the highest difficulty in testing course six. Throughout the other testing courses Dale was mostly avoiding proposing main ideas but was slightly adding his input to Mike’s already developed ideas. The team dynamics between the dyad also effected how they see the challenge levels of this game. As their problem solving throughout the testing courses solely depended on Mike, overall he reported higher challenge levels than Dale except in the last two testing courses. Dale did not spend too much time or effort on trying to solve the problems; however, he did have difficulties maneuvering through the game world. Mike did most of the problem solving easily by himself and discouraged Dale to perform some actions occasionally:

> *In room three, while Dale is standing still Mike was trying to solve the problem himself and was thinking out loud in a whispering way. When Dale tried to move towards the laser beam, Mike yelled: "Don't touch the laser." Dale: "I wasn't. I was just investigating." Then, mike picked up a cube and while trying to direct the laser somewhere else he asked Dale to run away.*
>
> *In room five Dale was trying to maneuver the laser from receptor to receptor to activate crushing plates and moving platforms, when Mike was trying to walk across. However after couple of failed tries Mike decided to switch roles. Mike: "Ok it is my turn at the laser." Dale ignores this and asks: "OK let's figure out where that door is that I need to hit." Mike gave in and explained Dale what he needed to do exactly and went back being the person who is walking across.*

It was not clear if Dale did not contribute to the problem solving activity as much because he felt discouraged or because he just did not feel the need, because the tasks were easy enough for Mike to figure out himself. As they took over the challenges provided in the hardest testing course of the chamber (testing course six), Dale made his biggest contribution to the problem solving activity by proposing a key idea. Since Mike was not able to quickly figure out how to solve the problem, this gave Dale a chance to observe and interact with the game world and eventually provide a solution.

The challenge ratings of the team indicated that the testing courses progressively got harder for them. However, the influence of this progressively increasing difficulty on their joint problem space was not clearly revealed from the observations of their gameplay. The way that their joint problem space was constructed through Mike's individual problem solving and sharing his ideas vaguely with Dale was ineffective. However, it can be observed that last testing course, the hardest one, encouraged Dale to participate more in the constructing of the shared problem space. Throughout the other testing courses, Mike mainly constructed his own problem space and then shared it with Dale to help him have a grasp of the problem.

Sensory stimuli elements.

Although it was observed that Dale was not as aware of his surroundings as Mike, the team still utilized some of the sensory stimuli elements during their gameplay. As they progressed in the chamber they observed the wall displays in couple of rooms and Mike briefly talked about them:

Mike: "Wall in front of you has all the warning signs on it. So we got pressure plates, lasers and something that can crush us."

Looking at the wall sign, Mike: "Lasers, crushing things, and is that water?"

Mike also paid some attention to the dotted blue lines while he was trying to solve the problem. This was observant only in case:

Mike examines the dotted lines coming out of the floor button he is on towards the first door and says to himself: "This opens that one (first door)." And then moves towards the second door to see if it is opened.

The most attention catching sensory stimuli element for the team was the audible clues. When they heard the ticking sound they (Mike) almost always reacted to it. Audible sensory elements helped Mike to solve the problem quicker, and sometimes even without knowing what would happen at the end, audible clues gave him a sense of what actions should be taken. For example in room two, when Mike heard the ticking sound, combined with his understanding of the problem space (noticing the multiple buttons, their locations and their signs) he knew right away that something was needed to be done in a quick manner:

Mike: "I am not sure what is clicking. We just have to hit the buttons really quickly."

After they pressed all the buttons together, Mike says: "Not what I expected, but wait. I heard a happy noise."

Mike also was aware that certain sensory stimuli elements meant a specific game object through his previous gaming experience with single player version of *Portal 2*. He incorporated his previously gained knowledge to his advantage and this helped him tackle a part of the problem that other teams struggled with fairly quickly:

Mike: "Do you hear singing?" Singing means turrets, OK. I need to blast the turrets. They are going to complain."

Unlike Mike, Dale did not have a clear understanding of the problem space during most of the chamber one, and therefore the sensory stimuli elements did not help him throughout the gameplay. For example, he was not aware that dotted lines were indications of the relationship between the buttons and the game objects they activate. In room one when Mike asked Dale about which door that a floor button opens he could not answer.

Mike: "What is that one (floor button) open?" Dale steps on it and days: "I am not sure."

Dale did not recognize the dotted line that changed color when he stepped on the floor button to indicate which door it had opened.

In the room two, Mike was ready to take an action to solve the problem after hearing the ticking sound and seeing the changing colors of dotted lines between the specifically marked tower buttons and marks on the ceiling. However, Dale had no idea what he had to do.

Mike: "I am not sure what is clicking. We just have to hit the buttons really quickly." Mike: "If you take your side." Dale: "What am I doing?" Mike: "I think we just have to hit the buttons really quickly." Dale: "So where are they located? There is one button" (He sees the button on the ground level) Mike: "You take the other side." Dale: "Oh Ok." Mike: "And you create a portal up top so you can go really quickly."

The only time it was observed that Dale was intrigued by a sensory element was when he saw an orange floor switch, he initiated a conversation about it, but did not get any response from Mike:

After investigating the orange floor switch through stepping on it and pressing a button to activate it, Dale: "This one, that we need a box for or something?"

Overall, it was not clear whether the sensory elements enhanced or inhibited the team's already weak collaboration. However, they definitely helped Mike during the problem solving process as feedfront and feedback mechanisms. The list of sensory stimuli elements that the team reacted and associated functional roles that played a part in the collaborative problems solving process is presented in Table 27.

During the construction of shared problem space the team benefited from sensory stimuli elements provided in the game to some level. As mentioned before, the weak common understanding constructed by this team made it harder for the researcher to examine the relationship between the game elements and the collaborative problem solving. However, it is safe to assume that some sensory elements such as audible feedback and visual directive elements were incorporated by Mike during the individual problem solving process which can be counted as part of their collaborative problem solving process.

Table 27

Sensory Stimuli Events in Chamber I

Sensory Stimuli Elements			Functional Role Triggered[a]	Example Participant Reaction
Visual	Decorative	Cameras	A-E	Mike tries to shoot the camera and jump up to try to interact with it or maybe to destroy it.
Auditory	Informative	Ticking noise	A-P B-C A-S A-I B-I	Mike: "I am not sure what is clicking. We just have to hit the buttons really quickly." Mike: "If you take your side." Dale: "What am I doing?" Mike: "I think we just have to hit the buttons really quickly." Dale: "So where are they located? There is one button" (He sees the button on the ground level) Mike: "You take the other side." Dale: "Oh Ok." Mike: "And you create a portal up top so you can go really quickly."
		Bing noise	A-E	Mike: "Not what I expected, but wait. I heard a happy noise." Mike: "Oh we got the ball."
		Turrets singing	A-P B-A A-I	Mike: "Do you hear singing?" Singing means turrets, OK I need to blast the turrets. They are going to complain."

Notes. [a]A: Mike B:Dale / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

In addition, some subtle sensory elements such as distinct color of game objects (E.g. white color of portalable surfaces) or symbols appearing on the screen (E.g. countdown symbol that appeared after pulling the switch) helped them develop a joint problem space.

Dale: "Can you target anything over here? You can't right? Because the floor under you, you can make a portal." Mike: "Umm there is one."

Mike: "Did I do it?" After pulling the switch numerous times. Dale: "Ok there has to be another switch around here and whole point of the countdown that we press it at the same time." Mike: "Oh Ok."

Clarity of the goals and rules.

Both of the teammates indicated that the goals and the rules of the game were generally clear (Table 28). In testing course six, however, Mike felt that they were more unclear compared to the other testing courses. During this testing course, Dale suggested the key idea that helped them solve the problem. Since Dale rated all of the testing courses equally clear, it is difficult to understand how the clarity of the goals influenced his role in the joint problem solving process. However, it can be observed that Mike's unclear understanding of the goals and rules in this testing course gave Dale a chance to step up and help Mike solve the problem.

Table 28

Reported Clarity of Goals and Rules

	Clarity of the Goals and Rules	
	Mike	Dale
Testing Course 1	24	27
Testing Course 2	21	25
Testing Course 3	27	24
Testing Course 4	24	25
Testing Course 5	28	25
Testing Course 6	17	25

Overall the repetitive goals of the game made it easy for the team to understand the problem space. Even though sometimes the end goal was not clearly discussed Mike almost always displayed a know-what-to-do attitude and he kept proceeded in the testing courses towards the exit doors. Clear goals of the game did not always help Dale in shaping his own understanding of the problem space. In fact in some cases, Mike's prompt understanding of the problem space and his quickly provided solutions hindered Dale's slow process of trying to understand what was going on around him.

The team did not have trouble comprehending the procedural and the system rules of the game. They were aware of constrains of their environments most of the times with the exception of trying to shoot through glass a few times. Also they knew that pressing buttons or placing boxes in floor switches would results with a pleasant outcome even sometimes they were not sure what that outcome would be.

Within Game - Across Group: Portal 2 and Collaborative Problem Solving

The simple design and the innovative concept of Portal game series puts this game among the most popular and enjoyable video games. Consequently, all the research participants who played the co-op version of this game reported, and also were observed, to enjoy the game thoroughly. Even though enjoyability was at the highest for all the teams, it cannot be claimed that collaborative problem solving process was effective for all the three teams. Each team played *Portal 2* as their first game in the study and completed a different number of sections in the game. A list of completed sections and number of research sessions for each group is provided in Table 29 to present the teams’ involvement with this game.

Table 29

Portal 2 Completed Sections for Each Group

Groups	Completed Sections	Number of Sessions
Group 1	Tutorial Chamber 1 (6 testing courses) Chamber 2 (6 testing courses)	2
Group 2	Tutorial Chamber 1 (6 testing courses) Chamber 2 (6 testing courses)	2
Group 3	Tutorial Chamber 1 (6 testing courses)	1

First group (Tom & Liz) displayed an unbalanced collaboration and individually heavy problem solving at the beginning of the game due to Liz’s lack of experience with PS3 gameplay. However, as Liz gained more experience the balance in their collaboration was restored. Even though the individual act of problem solving was mainly done by Tom, as a team, they communicated well and together they were able to build a joint problem space. Third group (Mike & Dale) demonstrated an ineffective collaborative problem solving process from the beginning to the end of their gameplay. Granted that they played Portals 2 for only one research session (other two teams played it for two research sessions and completed more chambers), their communication lacked the necessary attributes to develop a successful joint problem space. On the other hand, second group (Dan and Amy) was the most successful at collaboratively solving the problems faced during this game. The gap between the level expertise between the teammates in this group was lowest of all the groups. This helped them showcase a more balanced collaboration and equal contribution to the problem solving process. Specific influence of the game attributes on collaborative problem solving is discussed in the next sections:

Challenge.

This game provides puzzles with various levels of complexity and progressively introduces the players with new challenges. Teams differed in their perspectives of challenge levels of the testing courses based on their previous game experience and skills. While group one reported that testing course three (Total score: 15) and 6 (Total score: 15) were the toughest testing courses for them in chamber one, group two only found testing course three as very challenging (Total score: 28) and group three reported that testing course six was the most difficult (Total score: 20). Group one was more effective at communicating and collaboratively solving the problems when the difficulty levels were low for both of them or high for Tom. On the other hand, group two was encouraged more to be collaborative when they faced a complex problem, but not when they faced tasks that required them to be good at game mechanics (such as being able to quickly aim and shoot while in the air). Group three did not get affected as much from the changing levels of challenge. Overall, they were building a better common understanding of the problem when the challenge level was higher for Mike and it was taking a longer time for him to individually solve the problem.

Sensory stimuli elements.

Three teams that played this game differed considerably in their ways of acknowledging and utilizing sensory stimuli elements during their collaborative problem solving processes. Tom and Liz, as the least inexperienced team, paid the most attention to the sensory stimuli elements provided in the game to solve the problems that they faced. As the leader of the team, Tom was the person who was able to understand the utility of a sensory stimuli element and shared this with his partner. On the other hand, Dan and Amy did not pay as much attention to sensory stimuli elements unless they faced a challenging task. This mid-level experienced team was able to complete the easier tasks without discussing solutions that incorporated the help of sensory stimuli elements. However, when they needed the assistance of sensory stimuli elements, both team members were able identify their utility and converge on a solution using the clues the sensory stimuli elements provided. The last team, Mike and Dale, – another mid-level experienced team – displayed hardly any acknowledgement of sensory stimuli elements. As their conversational levels were significantly lower compared to the other teams, their usage of sensory stimuli elements as a team was not observable. Mike was able to solve all the problems with or without the help of sensory stimuli elements and only sometimes shared his understanding of the problem and how a sensory stimuli element played a role in understanding the problem with his partner. Specifics of the type and level of sensory stimuli utilization for each group is provided in the Table 30.

Table 30

Type and Level of Sensory Stimuli Utilization for Each Group

Type of Sensory Stimuli Element	Level of Utilization Based on Discourse		
	Group 1	Group 2	Group 3
Informative Wall Displays	High	None	Low
Indicator Lights	Medium	Medium	Low
Bright and distinct color and shape of game objects such as buttons, portalable surfaces, energy fields, etc.	High	Low	None
Symbols appearing on screen	High	Low	
Symbols and pictures displayed on floors, buttons, screens	High	High	Low
Moving Objects	High	Medium	None
Timer sound	Medium	Medium	Medium
Other informative sounds such as sound of a door opening	Low	None	Low

Clarity of goals and rules.

The goals of the game were clear for all of the teams; however, only the first team, Tom and Liz, expressed their understanding of the goals and occasionally exchanged ideas. Other teams did not feel the need to talk about the goals during this game. The rules of the game were learnt through trial-and-error by team two and three, and occasionally talked about if one teammate did not understand them. The first team, on the other hand, incorporated a more talkative approach in developing a common understanding of both the operational and procedural rules.

Chapter 4 Summary

This chapter provided the results of within case analysis for three first level cases: Within Case 1 – Group 1, Within Case 2 – Group 2, and Within Case 3 – Group 3. Each section presented detailed information about the player interactions and discourse that took place during the gameplay sessions. The influence of game design attributes were discussed at the individual group and session level. At the end of the chapter, results across all three groups were collapsed and presented in the within game across group section to identify the similarities and differences in the associations between game design attributes and collaborative problem solving across groups with different players and dynamics.

Chapter 5 - Lego Indiana Jones 2: The Adventure Continues

This chapter includes the analysis of two first-level cases that consist of group one, and three, as well as a within-game across-group analysis of *Indiana Jones 2*. During this chapter each group's gameplay, conversations, and interactions are thoroughly analyzed to examine the potential relationships between the game attributes and collaborative problem solving process. The results are presented under the following two sections: Within Case 4 – Group 1 (Tom and Liz), and Within Case 5 – Group 3 (Mike and Dale).

Within Case 4 - Group 1 (Tom and Liz) Playing Lego Indiana Jones 2

In the session analyzed, Tom and Liz played the game *LEGO Indiana Jones2: The Adventure Continues*. Neither of them played this game or any of the games in the LEGO series before. This was the third session that they played video games together, having played two sessions of *Portal 2* prior to this. The levels they played during this session included parts of the Kingdom of Crystal Skull and Raiders of the Lost Ark which are adaptations of the famous Indiana Jones movies. While Tom mostly played the game character Indy, Liz played several side characters such as Mac, janitor, Sallah, and Marion throughout the game. During the gameplay, they swapped controllers to be able to switch the game characters once. During this switch Tom played Marion and Liz played Indy.

Starting the gameplay.

The players started at the Hub World of this level where they explored the game world, and interacted with the game objects. This hub level also served as a very brief tutorial before the players took on the challenges of the upcoming story levels. During this part of their gameplay, Tom and Liz did minimal exploration and mainly stuck to the main objective of the level. The only task they had to overcome was to find a banana to give it to a monkey to in return receive a key, which then they could use to activate a train. Much like the other parts of the game, the hub level clearly indicated the necessary steps to be able to successfully complete the puzzle. Participants did not have to worry about finding a solution, but rather follow the clear instructions given by the game while trying to figure out what they can or cannot do in the game. They exerted most of their efforts on trying to understand the game controls and the way that they can interact with the game world.

> *At the beginning of the game Tom starts moving around as Indy, but Liz's character are not moving yet. Tom: "I think I am Indie most of the time, and if you hit start (Liz pressed start) there you go. But I think if we hit the triangle it said…Then we switch." Liz: "Yeah" Tom: "And we control the camera with the right joystick kind of like in Portal."*
>
> *Tom: "X is jump." They keep jumping around and accidentally Liz shoots and object in the game. Tom: "Oh what did you do?" Liz: "I pressed the square. It is too shoot" Tom: "So you have a gun. I can just punch things. Oh I have a whip"*
>
> *Tom: "Banana!" Liz: "Oh." They both go near the banana. Liz: "So how do we pick, oh" Tom whips Liz while trying to pick up the banana. Tom: "Sorry I don't want to do that."*
>
> *Tom: "How do I untie you? Because that is just going to drag you. Umm how about X, one of the triggers maybe? None of the triggers do anything." Liz: "No." She finally gets rid of the rope that is tying her down.*
>
> *Tom: "So it is good to know, once you got an object you can use circle to manipulate it, but it doesn't help."*
>
> *Liz: "How did you target?" Tom: "Once you hold square the crosshair show up." Liz: "Oh Ok."*

Here we see Tom and Liz investigating the game space and controls, experimenting to figure out the use of different elements. Through exploring their environment and talking to each other, together they discovered the available actions and how to interact with game objects. They learned that they can pick up game objects or shoot/whip. They also discovered that if they hit triangle they could switch characters, or if they pressed X then they could jump. In one instance Liz accidently shoot an object. This led Tom to inquire what she did. This incident shows how even random accidental actions could lead to sensory stimuli elements that help them create a shared understanding of their environment.

In general, Tom and Liz took advantage of the sensory stimuli elements during their collaborative problem solving. Although most of the visual sensory elements were prominently displayed on the screen and gave them direct instructions, some smaller stimuli elements also managed to arouse their curiosity during the gameplay.

> *Tom: "I think we have to move together and I think the little green arrow says come this way. Ahhh (a text on the screen appears to give them instructions: A monkey will give you an object in return for a banana. Find a banana.)*
>
> *When they approach an object in the game small blue and green arrows appear on the top of the object indicating that they can interact with the object. When Tom gets close to the bench the arrow appears and he asks: "What is this?" After Tom picks up the bench and walks around with it, Liz: "What is that?" Tom: "I can lift up the bench with my whip."*

Here Tom noticed the small arrows. These prompted him to inquire and discover that he could pick up the bench. Because he paid attention to these small sensory stimuli elements, he was able to understand how to use them.

The level of challenge reported was relatively low (Tom's score=2; Liz's score=6) for the hub level, and the team was able to quickly solve the problem after they understood the game controls and the rules of the gameplay. The team took 3 minutes and 40 seconds to complete this level. Clarity of the goals and rules were not clear for the team at this point, even though Liz reported a high score of 27 on a scale of 30. On the other hand, Tom rated the clarity of this level as 20. The open-ended nature of this game world made it harder for the team to understand the end goals or the rules of the game. For example they learnt that they needed a key, but only after they saw a text flashing on screen when they got close to a train. Had they gone to the other way instead of coming close to the train they might have spent a longer time trying to identify the goal of the hub world. Also since the game did not provide a tutorial session, the players had to figure out the controls of the game and the rules of the game themselves in the hub world and later in the story levels.

As it can be expected during the hub level while exploring and trying to understand their options, the team primarily displayed one type of functional role: execution of moves. As the clear directions given by the game provided very little room for discussion and negotiation during this level, the team did not to have any conversation around how to solve the problem. Tom executed most of the moves (82%) and identified the game controls and rules. Their conversations around how to play the game and what buttons to use to perform certain actions helped team members to develop similar understandings.

After finding the key and activating the train, the team proceeded to play the first story level, Kingdom of Crystal Skull. The story level started with a cut scene where Indy and Mac were captured and brought to a warehouse full of crates by KGB agents. This story level is analyzed in three parts for the purposes of this study. Each part is divided by a cut scene that indicated a small shift in the gameplay in terms of objectives and location. The second story level, Raiders of the Lost Ark, was also analyzed in four smaller sections in which the cut scenes created the divisions.

Collaboration.

Although the team displayed plentiful number of functional roles during their collaborative problem solving process, the depth and variety of these functional roles did not extent as much. Due to the less constricted nature of the game, the game utilized various sensory stimuli elements to gain attention and guide players toward the solution. Earlier in the game, the most important parts of the solution were easily provided for them as a text or shapes appearing on the screen when they got close to or obtained an object of interest. Since the detailed directions were provided for certain parts of the problem, when the team proposed a solution they did not elaborate on it. When any text appeared on the screen either one of them or both of them read the instruction out loud, and then either one of them would suggest what they should be doing next to accomplish it. In some cases, the required action was so obvious that they executed an action without discussing it.

> *Tom: "OK. So it is asking us to put a crate on the green floor plate (Text on Screen says: Can you find a crate to place on the green floor plate?). And here is a crate. Tom picks up and puts the crate on the green floor. Tom: "I don't know." Liz: "You might have to jump."*
>
> ---
>
> *Tom: "Switch to Indy to make use of his whip (reading text on screen). So Indy can use his whip, what can I... to target the lamp oh" After hanging on the lamp using his whip Tom is not sure what to do with this ability. He slides down while he is still hanging from*

the whip: "Oh now that it is longer, I can swing. I don't know if I am supposed to be getting anywhere in particular but."

Tom: "OK here is the vehicle." … Tom: "Yeah but what is this? Place vehicles on both pads to activate them (reading text on screen). So there is a pad, and there is a pad." He parks his car on one of pads. Tom: "Where is the other vehicle? There is a truck maybe that's the other one. No we can't go over there." He realizes where the other vehicle could be: "Oh come stand on this crate I bet there is another vehicle in it."

Here we see the different conversation examples that show how a prominently displayed sensory stimuli element (flashing text on screen) effected this team's collaboration. In the first example, they were both clearly directed to put a crate on the green pad. Tom quickly executed that action without discussion (but still explaining his actions to his partner.) In the second case, when Tom saw the text on screen about his whip, he realized that he needed to use it to jump across. He executed this move while Liz was exploring the game space herself. In the third example, we see that Tom read the flashing text on screen out-loud and quickly took action (parking his car). In all of these examples, after the obvious partial solution (hinted by the prominent sensory stimuli elements), Tom was still not sure about the next steps. This allowed them to still collaborate to solve the rest of the problem.

Also, at the beginning of the story levels, some of the conversation between the teammates reflected that they were still trying to figure out how to play the game more than how to solve the problem task given to them.

Liz: "So what else do we have to get. I just..." Tom: "So we have to find...There it is (he sees a second lamp) I don't know yeah. I am still figuring out the things we can do. So *like I can target things with my whip and then jump across. So now that I am here I wonder if there is anything"*

Liz: "Looks like I don't have my gun anymore." Tom: "You don't have your gun anymore?" Liz: "no" Tom: "Even if you hit the x" Liz: "Yeah I am just punching. Oh X? Tom: "Not X I am sorry the square." Liz: "Maybe I lost it." Liz: "Oh here is my gun. Ohh Ohh, now I get it. I put my gun away using the circle."

This example highlights how earlier in the story levels they still did not have a handle on the game controls. This was also pointed out during the hub level.

Overall, they mostly executed moves without discussing about it (45%), and sometimes they proposed (16%) and implemented (28%) ideas to solve the puzzles. The distribution of the functional roles between the two teammates (presented in Table 31) and the observation of their gameplay indicated that Tom was more active in contributing to the problem solving task by providing more ideas (80%) than Liz. Although it was observed that Liz was more comfortable playing this game than the previous one, during the collaborative problem solving process she still mainly relied on Tom's leadership. However, it was also observed that during this game Tom listened to Liz's suggestions and took them into consideration more often.

Table 31

Frequency of Functional Roles Assumed During Indiana Jones 2

		Crystal Skull P1		Crystal Skull P2		Crystal Skull P3		Raiders of Ark P1		Raiders of Ark P2		Raiders of Ark P3		Raiders of Ark P4		Tom Total	Liz Total	Total
		Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz			
Execution	N	39	32	8	8	2	0	20	13	16	13	28	28	37	27	150	121	271
	%	54.93	45.07	50	50	100	0	60.61	39.39	55.17	44.83	50	50	53.62	39.13	55.35	44.65	44.57
Proposal	N	15	3	3	0	3	0	6	3	8	3	23	8	18	3	76	20	96
	%	83.33	16.67	100	0	100	0	66.67	33.33	72.73	27.27	74.19	25.81	85.71	14.29	79.17	20.83	15.79
Implementation	N	14	18	6	4	10	6	9	6	7	10	23	9	26	22	95	75	170
	%	43.75	56.25	60	40	62.5	37.5	60	40	41.18	58.82	71.88	28.13	59.09	50	55.88	44.12	27.96
Modification	N	1	0	0	0	0	0	2	1	0	0	1	0	3	1	7	2	9
	%	100	0	0	0	0	0	66.67	33.33	0	0	100	0	100	33.33	77.78	22.22	1.48
Contestation	N	0	0	0	0	0	2	1	1	2	0	2	1	0	0	5	4	9
	%	0	0	0	0	0	100	50	50	100	0	66.67	33.33	0	0	55.56	44.44	1.48
Rejection	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acceptance	N	0	4	0	0	0	0	1	0	1	2	2	1	0	1	4	8	12
	%	0	100	0	0	0	0	100	0	33.33	66.67	66.67	33.33	0	25	33.33	66.67	1.97
Reasoning	N	0	0	0	0	1	0	0	0	0	0	3	0	2	0	6	0	6
	%	0	0	0	0	100	0	0	0	0	0	100	0	100	0	100	0	0.99
Testing	N	0	3	0	0	0	0	2	0	1	0	4	2	1	0	8	5	13
	%	0	100	0	0	0	0	100	0	100	0	66.67	33.33	25	0	61.54	38.46	2.14
Explanation	N	9	0	2	0	0	0	1	0	2	0	5	0	3	0	22	0	22
	%	100	0	100	0	0	0	100	0	100	0	100	0	100	0	100	0	3.62
Total	N	78	60	19	12	16	8	42	24	37	28	91	49	90	54	373	235	608
	%	98.73	75.95	61.29	38.71	32	16	68.85	39.34	31.09	23.53	21.56	11.61	21.33	12.8	61.35	38.65	100

Joint problem space.

Tom and Liz communicated effectively during their efforts in building a common understanding of the problem while playing this game. Even though Tom was more effective at providing the right solutions for the problem tasked faced, they both paid attention to their environments and conversed about the game objects and their perceptions on events taking place in the game. At the beginning of the game they seemed less sure about the possible actions and problem states. For example in the first two parts of the Crystal Skull level Tom and Liz were still trying to figure out the possible actions he can perform in the game and how that would be any use for the team to solve the problem:

Tom: "So I think if you jump, yeah, if you jump you can hold on, and this becomes a ladder and we can get up to that next area. I don't know if that's a good thing or not but it is an option."

--

Tom: "Oh I can pick this up." Liz: "Here we go." Tom: "I don't know what to do with it." Liz: "Oh we got to probably build it because there is two more or probably put a crate over there.

--

Tom: "Ok we have done something (they broke a crate)." Liz: "Ok and we need some more. What's in here? This one (Crate)" Tom: "Yeah because you can shoot all those crates. Or do we climb on it?"

--

Liz: "What is this stuff right here?" Tom: "I don't know. Punch it. Let's find out."

--

Liz: "What is this?" Tom: "I don't know." (Then Liz shoots at it)

--

Tom: "I can target the bottles. I am not sure why I would want to target the bottles."

In these different examples we see Tom verbalizing his lack of understanding of the problem states, actions, and association between states and actions. In one conversation, Tom proposed an action (climb the ladder and go to the next area) to Liz, but also indicated that he is not aware what the outcome of this would be. In another example we see the team getting confused about consequences of their actions. Tom indicated that they have done something (breaking a crate) but they were not sure what else they have to do (shoot or climb another crate). In other cases they performed actions (shoot, punch or target) without knowing whether it would help to reach the next problem state or not.

However it was observed that this confused state promoted more communication between the partners. They talked about almost everything that caught their attention. Even though they were not sure about the consequences of their actions, as part of building their joint problem space, they successfully identified the current problem states, possible problem solving actions, and the associations between the states and the actions:

Liz: "Ninjas!" (Problem state) *Tom: "Oh my gosh. Oh, for crying out loud." Together: "And monkey with the key."* (Problem state)

Tom: "Now that I have done that (placing the torch on a slot on top of the snake pit) (action), *we leave the torch in there* (problem state), *the snakes go away* (association). *Liz: "And then..." Tom: "And then we can go get that reflector dish and put it in its holder* (action)."

Tom: "What happens if like you stand on? (Action) *There is this two lights on the floor.* (Problem state) *I wonder what happens if you stand on one and I stand on one."* (Action) *Liz: "Ok." Tom: "But it doesn't seem to be doing anything.* (Cannot identify an association)*" … Tom: "First thing we have to do is get ourselves a ladder*.(Problem State)*" Liz: "Where is the ladder? Ohh." (He completes building the ladder) Tom: "Now we have the ladder we can jump up and put the fire out.*(Problem state, action, and association between them)*" Liz: "OK"*

Tom: "I don't know what we have to do. He is (he walks up to the Nazi soldier and cut scene starts.) Oh he was on a glass thing and I went to get close to him but now" Liz: "We ended in a new room. (Problem state) *" Tom: "We ended in a new room but also something is blowing up* (Problem state)... *Oh it looks like car and also he just got burned* (Action).*"*

Liz: "Maybe we need to move that one (Action).*" Tom: "It is a good idea. But he still needs to target this one (Reflector 1)* (Action)*" Liz: "Maybe one of us has to stand here* (Action). *I don't know." Tom: "Certainly worth a try."*

Tom: "We jump into that (Action) *and we can grab the key* (Action). *Aahh now we can move stuff* (Association)." *Liz: "Do you have to stand back on it again* (Action)*?" Tom: "Yeap but it lowered it* (State). *I bet now yeah different thing* (Association).*" This time the* *beam hits the lower structure and reveals an opening which concludes the puzzle for this section.*

An important part of the joint problem space is also the identification of the goals. Unfortunately, during this game Tom was the only person in the team who was able to identify the end goal of the sections. However, as we can see from the conversation below, the fact that he talked with his partner about the possible end goals allowed the team to have a common understanding.

Tom: "It looks from the like starting sequence like we were supposed to be that we were trying to find a crate of some sort." Liz: "Right"

Tom: "We can get back up here. But there doesn't seem to be anything though. Like this seems like the mission end. We keep doing things and we end up here."

Tom: "Now that, that (statue) moved over, because we are trying to get out I would imagine. Liz: "Right."

Liz: "I think there is something we have to build." Tom: "I don't know. It feels like when we kill these guys it makes sense, because we have four these guys on the foot that we need to kill." Liz: "So messed up." Tom: "So let's go over to the other side so maybe we can find them again." Liz: "Another sword." Tom: "Yeah. But we need to find the Sherpa looking people. There."

Tom identified the goals of this game based on his observations of either the cut scenes or other game interactions. He shared his understanding of these goals with Liz in most cases.

Certain parts of this game put the players into fast paced fighting and puzzle solving situations at the same time in which the team members still managed to share their understanding of the problem space.

Tom: "So before we get resuming, this looks like it is going to be a boss fight. See how we each have health and he also has a certain amount of health. (Discussing current problem state)" Liz: "So I got to shoot. (Awareness of possible actions)" Tom: "So you have to shoot him and I will try to run up the boxes and see if I can punch him. (Awareness of possible actions)" Liz: "OK" Tom: "Because I don't have any long range stuff the way that you do (Association that relates the states and actions). OK ?"

Tom: "OK so with this level it looks like we have two things that we can go stand on over on that side (Discussing current problem state), so I might..." Liz: "Does that mean press fire? (Awareness of possible actions)" Tom: "It looks like it. So that might be a good thing to do right away, because otherwise I don't know what the rest of the room looks like."

Tom: "I am going to pause again so we can talk. Now we know that standing on those two things has the fire come out of the vehicle he is on (Association that relates the states and actions). I feel like what we should do is maybe knock him off the vehicle and then try to burn him (Awareness of possible actions). But I don't know. I mean does that seem like a good idea?" Liz: "Yeah."

As can be seen here, they utilized a different strategy to overcome these challenging sections. They paused the game to discuss their options. During these paused moments they observed their environment and strategized their actions before getting in the heat of the action.

Another way to examine the level of joint decision-making that this team was involved in is to look at the collaborative completion discourse that took place during the game. As the team discussed on their shared knowledge of the problem space, they started jointly producing compound ideas to solve the problems. The following examples showcase how Tom generally led the conversations and how he was the main idea provider in most problem solving activities.

Tom: "Now if we go stand in the light maybe." Liz starts building the Lego blocks.

Tom: "Oh what were you just doing because it worked?" Liz: I was pressing."

At the same time they say, Tom: "Oh now we can build." Liz: "Pressing the circle."

Tom: "Yeah." Tom and Liz build the robot.

Tom: "Ok we have done something." Liz: "Ok and we need some more. What's in here? This one (Crate)" Tom: "Yeah because you can shoot all those crates. Or do we climb on it?" Liz shoots the crate. Liz: "Ok more coins. Did I need like more building?"

Tom: "No there wasn't anything left. But can we manipulate this? What happens if we try to actually make this? Because we just built a robot it looks like."

Liz: "Yeah." Tom: "And I know that we got kidnapped, so maybe the robot will break us out?" Liz: "I hope so."

Tom: "We can get back up here (crates on the right side). But there doesn't seem to be anything though. Like this seems like the mission end. We keep doing things and we end up here." Liz: "Maybe go stand on the box"

Tom: "So it says switch to Mac to make use of the gun. Can you shoot this crate maybe? Is that something that becomes an…"

Liz shoots the crate and it opens up. Tom: "Oh, OK." Liz: "Blue (arrow). You?"

Tom: "I have to do something with it, but I don't know (he picks up a Staff of Ra) Oh Ok."

Tom: "We both need one." Liz: "OK. How did you pick it up?" Tom: "Umm circle."

They both pick up a Staff of Ra and place it under the light. This results with a cut scene where the statue comes to life and run towards the crates on the right side.

Liz: "Oh why did it do that?" Tom: "Because I bet we can go though there now."

In this example taking place in the Crystal Skull level, Tom and Liz’s actions and discourse reveals how they complete the problem solving activity together. In this section of the game they were trying to figure out what they need to do to solve the puzzle without having a clear understanding of the end goal. Even though Tom generally led the conversation by proposing most of the ideas, they produced compound solutions which indicated the development of their joint problem space. In this example, Liz found out that they can build something by pressing circle button. When Tom realized what Liz discovered he joined in the action. They built a robot together and then discuss about the possible uses of this robot. They eventually figured out how to make use of the robot by exploring their environment, paying attention to the sensory stimuli and talking to each other.

In another example in the Raiders of the Ark level, Tom and Liz created a shared understanding of the problem and collaboratively completed a section of the puzzle. Tom’s dominance over the conversation and providing solutions can still be observed in this conversation. In this particular section they were trying to figure out how to get rid of the snakes and place a reflector dish in an underground room:

> *While walking around with the reflector dish in his hand Tom sees a white arrow flashing on top of the snake pit. Tom: "Oh there is where I am supposed to put it." When he tried to put the dish on the spot with the arrow, the dish falls into the snake pit. Tom: "That didn't work." Then he takes one more step and falls into the snake pit himself. Tom: "So we have to clear the pit.”*

Liz enters the snake pit to kill them with her shovel, but she dies. Liz: "I thought jumping into it would…" Tom: "Fire maybe?" Tom: "How do we? Yeah, because we have to clear out that snake pit, so when we want to do anything else we can"

Liz: "I am chopping all around us." While climbing the wooden scaffolding, Tom: "Yeah that's a good thing." Liz: "Oh you got up there. What is that?" Tom: "Fire. And I bet when I have fire I can clear this snake pit. Yeah. OK. The snakes, they don't like fire." He puts the torch above the snake pit. Tom: "Now that I have done that, we leave the torch in there, the snakes go away." Liz: "And then?" Tom: "And then we can go get that reflector dish and put it in its holder." Liz: "Right there?" Tom: "Right there." Tom: "That didn't work." Liz: "What?" Tom: "What about..." Liz: "Put it right here?" Tom: "No because look whenever you pick that (reflector dish) up, the little arrow here starts flashing on that pulley thing there. I feel like there is got to be a way to turn this key. There is got to be a key or something we can...hmm." Liz: "We can't whip it up there?" Tom: "We can try. I am here I can try (he takes out the whip and the crosshair only appears on his partner) Only target here is you that I can whip." Liz: "Maybe whip that and try. I don't know." Tom: "Yeah I mean. (He whips her.) No that just ties you up. Sorry." Tom: "What else is in this room? There is the torch, there is bunch of snakes which I get freaky with, and is there a key or something up?" Tom: "So up here." Liz: "Maybe we need to get up there somehow." Tom: "Well we do but I can't get up there because I am afraid." Liz: "I don't know how I am going to get up there." Tom: "Come this way." Liz: "Oh there is another beam (reflector dish) up there." Tom: "Yeah. Also there is umm ways that you can get up there." Tom: "If you kill all the snakes we can go up there together."

After they climb up the wooden scaffolding, they realize it is not going to help them.

Tom: "Hmmm you know there got to be a key. Can we push this? Does this count as? It is not the ..." At the same time, Liz: "Checkers." Tom: "Checkered."

Tom: "So we can pick up the reflector dish and we can put it only back where it was. I mean you know like it should connect in there somewhere." He tries to put the connector dish in its place it but it falls down next to the lever along with him. Tom: "It seems to me...(He presses a button right next to the fire that was placed in the snake pit t and it pulls the lever and brings out a platform) Oh now I kind of feel silly." Liz: "Oh you found something." Tom: "Yeah there was a lever there. So now I bet we can get everything we need to get."

Tom and Liz found a solution to these problems together by discussing and performing several ideas. They walked into the snake pit and realized that they die if they do that. This led them to consider different solutions. Even though there were no clues in the game about getting rid of the snakes with fire, this idea was suggested by Tom (possibly based on his previous knowledge of Indiana Jones movies or general knowledge about snakes). After they got rid of the snakes they continued to provide solutions regarding how to put the reflector dish up in its holder. While Liz only suggested to whip the reflector dish up in the holder, Tom suggested more reasonable solutions. They executed all of the proposed solutions. Eventually, Tom realized that he could pull down a lever that was next to the torch holder above the fire pit.

In another example in the last section of the Raiders of the Ark, it can be observed that the team had difficulty constructing a shared understanding. Although they were good at collaboratively completing the problem task for the most of time, at the end of the task they encountered a slight lack of mutual understanding.

Tom: "OK so what other variables can we or have we changed. We took the torches and we put them in the two sconces. We pulled a switch on each side we got a spear on one side and a spear up there for the buildy thing. And then..." Liz: "The jumps that we did." Tom: "I guess we could make him tip. I feel like the tipping seems like it should have been important. You know if I could like grab his arm…" Liz: "Yeah like if both of us should have done it." Tom: "Right." Liz: "More weight." Tom: "Except I don't think you know…" Liz: "That I can't jump that high?" Tom: "Actually can you try coming up? Like if I am standing there can I catch you I wonder? (They try and it doesn't work) No sorry" Tom: "What if you try to jump from closer, if I hold the torch here. Can you? Is there any way you can get up there" Liz: "I was able to jump up there (on Statue) that much." Liz actually jumps on the statue but Tom did not see or understand what she is trying to accomplish. Tom: "Yeah I mean we can just try sort of." Liz: "We were able to jump on the spear and onto the other one." Tom: "Oh that's an idea." Then Tom realizes that she can now jump on the spear attached to the statue directly. Tom: "Oh now you can jump on the spear. We both..." Their weight pulls down the statue more and breaks the chain between the two statues. Liz: "Ah yeah."

While Liz was trying to communicate an idea to her partner, Tom seemed to be pre-occupied with his ideas and did not fully understand what she was trying to suggest. After he saw her conduct the move of jumping on the spear he realized that was the missing step in their solution to find an escape route. This conversation above represents a great example of when Liz is more dynamically involved in the problem solving activity.

Influence of game elements on collaborative problem solving

Challenge.

Based on the reported challenge ratings (Table 33), it can be assumed that generally Liz felt that she was more challenged then Tom.

Table 32

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Crystal Skull P1	Tom	1	39	15	14	1	0	0	0	0	0	9
	Liz	10	32	3	18	0	0	0	4	0	3	0
Crystal Skull P2	Tom	3	8	3	6	0	0	0	0	0	0	2
	Liz	10	8	0	4	0	0	0	0	0	0	0
Crystal Skull P3	Tom	3	2	3	10	0	0	0	0	1	0	0
	Liz	0	0	0	6	0	2	0	0	0	0	0
Raiders of Ark P1	Tom	5	20	6	9	2	1	0	1	0	2	1
	Liz	10	13	3	6	1	1	0	0	0	0	0
Raiders of Ark P2	Tom	3	16	8	7	0	2	0	1	0	1	2
	Liz	8	13	3	10	0	0	0	2	0	0	0
Raiders of Ark P3	Tom	3	28	23	23	1	2	0	2	3	4	5
	Liz	12	28	8	9	0	1	0	1	0	2	0
Raiders of Ark P4	Tom	3	37	18	26	3	0	0	0	2	1	3
	Liz	14	27	3	22	1	0	0	1	0	0	0

The team displayed more variety functional roles during the Raiders of the Ark level which was rated more challenging than the Crystal Skull level on average. While Tom perceived that the part one of Raiders of Ark story level was the most challenging, Liz reported that the part four of the Raiders of Ark level the most challenging. Overall, the part one of Raiders of Ark was one the high challenging sections for both of the team mates. During this section of the game, team members tried to solve the puzzle while avoiding a beam that a Nazi soldier was aiming at them. Therefore, the gameplay mechanics were slightly more difficult than just trying to solve a puzzle without disturbance. In addition, the problem task during this section was more difficult than some of the other levels. The difficult task combined with difficult gameplay mechanics reduced the number functional roles that are more collaborative in nature. They proposed lesser solutions and executed individual moves more often. Also at the end of the section they completed the final piece of the puzzle by random luck, instead of developing a solution collaboratively.

In the part three of the Raiders of the Ark, the team displayed more variety and number of functional roles. This section was reported challenging for Liz, but not really challenging for Tom. This section did not include any difficult problem tasks or gameplay mechanics; however, it was consisted of several small intricate tasks that lead the players towards the final state. Solving each of these small intricate tasks cultivated more of the functional roles such as proposing, implementing, and testing ideas as well as discussing the ideas as a team more than other sections. Also, during this section Liz proposed and tested more ideas than any other sections of the game.

Even though Tom reported that the part four of the Raiders Ark was not very challenging, during the research session it was observed that the team had difficulty playing the section and solving the puzzle. It was during this session that they had to switch controllers because the jumping from one spear to another without falling on the spikes was too hard of a move for Liz. Tom suggested that they switched controllers so that he could complete that part of the gameplay as it was necessary part of the solution. After they overcame the difficult gameplay mechanics of this section by switching controllers, the team encountered a halt in their problem solving as they could not figure out the final step of the solution. The solution came after Liz executed a move (jumping and holding on a spear attached to a statue) that helped Tom to realize that he can also execute the same move without realizing that this was the necessary step to take to complete the puzzle. During this section Tom proposed most of the ideas and Liz generally followed his lead and implemented what he suggested. They also modified some of their initial ideas the most during this section.

Although overall Liz found this game more challenging then Tom, most challenging parts of the game for both the team mates were in the Raiders of the Ark story level. It was during this level of the game that they had more two-way conversations and more collaborative completion of the problem tasks as well. This two-way conversation and collaborative completion of problem tasks can be seen in the example conversation given in previous sections (pg. 204-207). These conversations took place in this part of the game (Raiders of the Ark) where the differences in the perceived challenge levels were high. Part one of this level was also reported as difficult by both team members due to the challenging act of solving a difficult problem while in the middle of a fight scene.

> *After watching the cut scene where the beam destroys two Lego mans, Tom: "So don't get hit by the beam." Tom: "What can we do over here? Oh I can pick this up. We both can pick stuff up together." Tom: "I will distract him if you can throw that thing at him." Tom: "I have a banana. Can I throw the banana at him? (He tries) Sure I can. Did I hit him? No." Tom: "OK what else can we do? What would help? Ah here is something else we can build, because the pieces are shaking."*

The team starts building the moving Lego pieces, Liz:" Umm a checker board." Tom: "Ah a reflector dish? So now if we build something..." Liz: "Can we move it?" Tom: "Yeah I bet we can." (Completing each other's thoughts)

They built and move the reflector dish which disables the Nazi soldier's beam and takes out one of his lives. Also he starts throwing dynamites at them. Liz: "And we have to do that two more times?" Tom: "Yeah how it looks like." Tom: "It looks like we are going to have another reflector dish in a minute (after seeing the moving Lego pile.)"

They move the second reflector dish. Tom: "Did that do it? Nope it didn't." Liz: "Maybe there is another one over here?" Tom: "Maybe. Ops, no we got him. We just had to get him to adjust the beam." Another one of the Nazi soldier's lives is gone, and also he starts throwing dynamites at them. Tom: "So he starts throwing that things and the goons come back. The good thing with the goons is that I think if we hit them three times they die." Liz: "This one doesn't want to go." Tom: "He is blocking you off. Let me see if I can tie him up." Liz: "He has a gun." Tom: "Oh he is back to shooting at us and there is a goon." Liz: "There is goon too?" Tom: "Yeah." Tom: "I feel like there might be a third reflector we have to do, but." Liz: "Don't know where it is yet." Liz: "What is that up there?" Tom: "The reflector dish." Liz: "So yeah." Liz: "Can we turn it somehow?" Tom:" Yeah that would be good. No I can't target it with my whip." Liz: "Maybe we need to move that one." Tom: "It is a good idea. But he still needs to target this one (Reflector 1)" Liz: "Maybe one of us has to stand here. I don't know." Tom: "Certainly worth a try." Tom: "I see this. If we move this one at all then it doesn't get picked up." Tom: "I definitely feel like it is something to with getting up to that other one (reflector)."

Tom: "What about here? Is that something we can do stuff with? No" Liz: "Why does that little thing?" Tom: "So we can pick up the furniture and we can throw the furniture at him which stuns him for a little bit" Liz: "Is this something building, because it is shaking." Tom: "Yeah." Liz: "Maybe it is another." Tom: "Maybe it is something we can use to reflect. (they build it) It is a chair." Liz: "Chair."

They accidentally solve the puzzle while moving the reflector dishes around.

Tom: "Oh we got him." Liz: "How?" Tom: "I don't know how."

As it can be seen in the conversation between them, Tom and Liz still successfully identified their current problem state and discussed about the possible that they can perform to complete the task. They also completed their partner’s ideas and took turns in developing solutions. Therefore, it can be assumed that as the challenge level increased, the necessity for them to work together to solve the problem arose. However, at the end they completed this task by random chance.

Sensory stimuli elements.

As mentioned earlier, this game provided a lot of guidance through prominently providing visual sensory stimuli elements. These visual elements included flashy text appearing on screen to give directions and instructions to the player, small arrows or crosshair appearing on objects that needs to be interacted after a player picks up an object, sparkling patches on the grounds, and moving game objects, etc. Tom and Liz reacted to almost all of the sensory stimuli elements and incorporated them during their collaborative problem solving process. They read all the text appearing on screen out loud and acknowledged even the smallest color difference or movement. All of these visual sensory stimuli elements that they encountered awoke their curiosity and resulted with a conversation. Here are samples of conversations that took place in the story levels upon the team's encounter with a visual sensory stimuli element:

Tom: "Switch to Indy to make use of his whip (reading out loud). So Indy can use his whip, what can I... to target the lamp oh (as he sees the crosshair appearing on the lamp)"

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Liz: "Do we need this? Whatever this red thing is?" Tom: "Maybe. It looks like.. Oh there is another crate."

Liz: "It has both of our arrows on it. Does it mean that both of us have to carry it?" Tom: "I think it means either of us can mess with it. Whereas like if it needs the gun it only has green arrow or if it needs the whip it only has blue arrow." Liz: "OK."

Liz: "Is this something building, because it is shaking." Tom: "Yeah." Liz: "Maybe it is another." Tom: "Maybe it is something we can use to reflect. (they build it) It is a chair." Liz: "Chair."

Tom: "Looks like it wants us to go this way. Maybe. (Green arrow popped on the screen) Yeah, see there is like a trail of gold."

Liz: "What is this?" (Looking at the lock that has an blue arrow flashing on it) Put it in there?" Tom puts the key in the lock and says: "Yeah."

Liz: "What is that lighting up? What is that?" Tom: "Bananas you can pick and throw."

Liz: "Oh what is this? Fire (actually it is just a pool of red snakes)" Tom: "Yeah." After seeing the text on the screen, Tom: "Oh no it is a snake pit. All that red stuff is a snake pit. So I can't go in there. Because my character freaks out at snakes."

Liz: "What is this? (looking at the white arrow)" Tom: "That's the spot where I have to put the staff."

Tom: "And there is nothing back up here." Liz: "And that little red light doesn't do anything?" Tom: "I feel like it should, but I think it is just supposed to be something fancy."

While walking around with the reflector dish in his hand Tom sees a white arrow flashing on top of the snake pit. Tom: "Oh there is where I am supposed to put it."

Tom: "So there is five of those guys with sort of big guns I think. If I had to guess I would say that's what that (picture of head of five guys on the top of the screen) meant."

In these examples, we see that Liz’s curiosity got provoked by the flashing arrows or noticeable colors. This led her to ask questions about the sensory stimuli elements and objects that they are related to. These snippets of conversations exemplify how some of their conversations were triggered by the sensory stimuli elements.

The abundance of the visual sensory elements during this game instigated plenty of conversation between the team mates around the sensory stimuli encountered. These conversations showcased variety of functional roles including proposing, agreeing, contesting, reasoning, and implementing.

Tom: "So it says switch to Mac to make use of the gun. Can you shoot this crate maybe?(Proposing) Is that something that becomes an.." Liz shoots the crate (implementing) and it opens up. Tom: "Oh, OK (agreeing)."

Liz: "What is this?" Tom: "We might have another target. The bulls-eye sort of is there. If you aim your gun to it (proposing)." Liz aims at the target and crosshair shows up. Tom: "Yeah.(agreeing)"

Tom: "And once you jump you can use that as a ladder (proposing). And I don't know why we should be doing this (contesting). This might have nothing to do with the actual mission, but might be important." Liz: "How did you get up there, Oh (She figures it out herself)" Tom:" And then, ohh, it is checkered floor which means we can push this box of stuff." After Tom pushes the box down, metal tools fall on the floors. Liz: "Some tools. Oh." Tom: "So they are getting stuck on that crate magnetically." Liz: "That means we might have to go up there and shoot (proposing)." Tom: "Yeap (agreeing)."

Tom: "That didn't work (contesting)." Liz: "What?" Tom: "What about..." Liz: "Put it right here?" Tom: "No (contesting) because look whenever you pick that (reflector dish) up, the little arrow here starts flashing on that pulley thing there (reasoning)."

Tom: "What happens if like you stand on, there is these two lights on the floor. I wonder what happens if you stand on one and I stand on one (proposing)." Liz: "Ok (agreeing)." Liz stands on the spot suggested by Tom (implementing).

The Table 32 presents the related sensory stimuli elements and the functional roles more in detail. Overall it can be inferred that the abundant and blatant style of the sensory stimuli elements in this game definitely helped the team members assume some of the functional roles that are more collaborative in nature. However, in general the team members executed a lot more moves themselves, and they relied heavily on sensory stimuli elements to solve the puzzles.

Table 33

Sensory Stimuli Events in Indiana Jones 2

Sensory Stimuli Type		Functional Role Triggered[a]	Example Participant Reaction
Visual	Flashing Arrow, Color/Shape	B-E, A-X B-E	Tom: "OK. So it is asking us to put a crate on the green floor plate. And here is a crate. I don't know." While Tom tries to pick up one of the crates, Liz picks up the right crate. Tom "Oh there you go. So that might be the crate that we need to pick up" Liz brings the crate to the green plate: "Now how do I..?" Tom: "Circle again maybe puts it down."
	Flashing Text	A-E	Tom: "Switch to Indy to make use of his whip (reading out loud). So Indy can use his whip, what can I... to target the lamp oh"
	Color/Shape	A-E	Tom: "Oh Ok so maybe I can grab and push this. The checkered floor I can push the objects." He looks around the object a little bit and figures out that he needs to be behind the object to push it "There you go. Maybe I can hand you this."
	Color/Shape	A-P B-A A-I B-I	Tom: "What happens if like you stand on, there is these two lights on the floor. I wonder what happens if you stand on one and I stand on one." Liz: "Ok."
	Flashing Arrow	A-P B-A B-I	Tom: "But as the gun person you can. Maybe there is something down here that you can shoot again. Like that one of these two crates. Maybe we can get another pile of stuff." Liz: "OK."
	Crosshair	A-P B-I	Tom: "How about this though. The crate up there. See also when I can mess with stuff with my whip, I get a corsair kind of like that.
	Moving Lego Pieces	B-E	Tom: "Oh it (Lego pile) all started to move." Liz: "Hmmm" Tom: "OK."
	Flashing Text	A-P B-I	Tom: "So it says switch to Mac to make use of the gun. Can you shoot this crate maybe? Is that something that becomes an.." Liz shoots the crate and it opens up. Tom: "Ohh, OK."
	Color/Shape, Crosshair	A-P B-I	Liz: "What is this?" Tom: "We might have another target. The bulls eye sort of is there. If you aim your gun to it." (Liz aims at the target and crosshair shows up) Tom: "Yeah"

Table 32 (*continued*)

Sensory Stimuli Type	Functional Role Triggered[a]	Example Participant Reaction
Crosshair	A-E, A-P A-I	Tom: "Find a spear, OK. Hold square to target wall sockets, which I bet must be these things (he is standing under the coins, aims at the sockets) Yeah, so the read things are the spears or the target for the spears" Liz: "So I have to shoot them?" Tom: "No if you pick up a spear. you have to pick up a spear from this case with (circle), and hold the square."
Flashing Text	A-E	Tom: "OK here is the vehicle."
Flashing Text, Color/Shape	B-E	Tom: "Yeah but what is this? Place vehicles on both pads to activate them. So there is a pad, and there is a pad."
Color/Shape	A-P B-A-B-I	Tom: "You might have to jump up there." Liz: "OK."
Flashing Arrow	B-P A-I	Liz: "What is this?" (Looking at the lock that has an blue arrow flashing on it) Put it in there?"
Flashing Text	A-P B-I	Tom: "Do you have a." Liz: "OK I need a sword." Tom: "OK." Liz: "All I have a shovel." Tom: "Ok if you hit the circle button that you can go through every weapon you have, so if you ever picked up a sword. Let me see what I can do."
Flashing Text, Color/Shape	A-X B-E	After reading out loud the text that appeared on the screen Tom: "And you do have a shovel." Liz tries and can't get the digging action started Liz: "So how do I? Dig this up?" Tom: "If you dig that, I imagine with circle or the square"
Flashing Arrow	A-P A-I	While walking around with the reflector dish in his hand Tom sees a white arrow flashing on top of the snake pit. Tom: "Oh there is where I am supposed to put it."
Flashing Arrow	B-P A-C A-S B-E	Tom: "That didn't work." Liz: "What?" Tom: "What about..." Liz: "Put it right here?" Tom: "No because look whenever you pick that (reflector dish) up, the little arrow here starts flashing on that pulley thing there."
Color/Shape	A-P A-I	Tom:" And then, ohh, it is checkered floor which means we can push this box of stuff."
Color/Shape	A-P A-I B-I	Tom: "Oh come stand on this crate I bet there is another vehicle in it."
Color/Shape	A-P A-I B-I	Tom: "OK so with this level it looks like we have two things that we can go stand on over on that side, so I might..." Liz: "Does that mean press fire?" Tom: "It looks like it. So that might be a good thing to right away. Because otherwise I don't know what the rest of the room looks like."
Moving Lego Pieces	A-P A-I B-I	Tom:"Ahh here is something else we can build, because the pieces are shaking."
Color/Shape	B-P A-I	While building the moving Legos, Liz:" Umm a checker board" Tom: "Ahh a reflector dish? So now if we build something..." Liz: "Can we move it?" Tom: "Yeah I bet we can."
Moving Lego Pieces	B-P A-I B-I	Liz: "Is this something building, because it is shaking." Tom: "Yeah." Liz: "Maybe it is another." Tom: "Maybe it is something we can use to reflect. (they build it) It is a chair." Liz: "Chair."
HUD	A-P A-I B-I	Liz: "I think there is something we have to build." Tom: "I don't know it feels like when we kill these guys it makes sense. Because we have four these guys (four head pictures on the screen) on the foot that we need to kill." Liz: "So messed up." Tom: "So let’s go over to the other side so maybe we can find them again."
Color/Shape	A-P B-I	Tom: "Also, there is stuff. I think you can dig over here. See how the ground is shiny"

Table 32 (*continued*)

Sensory Stimuli Type		Functional Role Triggered[a]	Example Participant Reaction
	Color/Shape	A-P A-I B-I	Liz: "Can we go up there?" Tom: "It is also on a checker so we can push it." Liz: "Maybe."
	Color/Shape	A-P A-X B-I	Liz: "Is there anything else I should get here?" Tom: "Can you jump up there to get the blue gem? Because they are worth a lot, but if not don't worry."
Audial + Visual	Flashing Arrow, Color/Shape, Ticking Noise	A-X B-I, A-P B-P A-A A-T	Tom: "So I think there might be, if we take the jeep over that (race start line) there is a race track. So if you pass over that, then you have not long to get over the next one is." Liz: "Something has to go here (looking at a green arrow pointing on a plate on the floor)" Tom: "OK. Let me try something." Tom: "I am wondering if we just have to get the jeep there, you know like drive through the check point." Liz: "OK," Tom: "And get the jeep there in the five seconds or whatever that we have"

Notes. [a]A: Tom B:Liz / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

Throughout their problem solving activity, Tom and Liz incorporated several visual sensory stimuli elements. While some of the sensory stimuli elements helped them through awaking their curiosity and catching their attention, some sensory stimuli elements were purposefully used by the teammates to be able to identify possible actions to solve the problem. For example, as soon as Tom realized that a crosshair was appearing on game objects that he can interact with, he started to aim his weapon and moved it all around the game world to be able to identify what was intractable at that point.

Tom: "You have a thing that you can shoot over on this. I mean anytime that you are holding the circle and the crosshair show up you can shoot the thing." Liz: "Cool."

Tom: "Here there is an extra spear, so I don't know what we can do with that spear, but we have a spear now. (He aims the spear and moves the camera around the room until crosshair appears on an object) ah." Liz: "Oh right there."

They also communicated almost every time when they saw a text appearing on the screen. This helped them create a common understanding of the problem states and increased their awareness of the available actions. These text directions also guided them towards the solution. Here is an example of how the team's problem solving activities were shaped after seeing the flashing texts:

Text on screen: "Hold (square) to aim your gun at the target, then release the button to shoot."

Team's reaction:

Tom: "I can target the bottles. I am not sure why I would want to target the bottles, but as the gun person you can. Maybe there is something down here that you can shoot again. Like that one of these two crates. Maybe we can get another pile of stuff." Liz: "OK." Tom: "How about this though. The crate up there. See also when I can mess with stuff with my whip, I get a corsair kind of like that." Liz shoots it and they get a box with pile of Lego. Liz: "It has both of our arrows on it. Does it mean that both of us have to carry it?" Tom: "I think it means either of us can mess with it. Whereas like if it needs the gun it only has green arrow or if it needs the whip it only has blue arrow." Liz: "OK." Same text appears again. Tom: "Still don't know what the target might be." Tom: "Oh it (Lego pile) all started to move." Liz: "Hmmm" Tom: "OK."

Their problem solving activity was also influenced by other sensory stimuli elements such as flashing arrows, sparkling ground patches, life meter of the enemies appearing on the screen, and cut scenes.

Liz: "Blue. You?" Tom: "I have to do something with it, but I don't know (he picks up a Staff of Ra) Oh Ok."

For example, in this discourse example, we can see that Liz was referring to a blue arrow that appeared on top of an object which indicated that only Tom could interact with it. Tom realized that he needed to do something and moved towards the blue flashing arrow.

While walking around with the reflector dish in his hand Tom sees a white arrow flashing on top of the snake pit. Tom: "Oh there is where I am supposed to put it."

In another example, the realization of where to place a reflector dish came to Tom after seeing a white flashing arrow.

Tom: "No because look whenever you pick that (reflector dish) up, the little arrow here starts flashing on that pulley thing there. I feel like there is got to be a way to turn this key. There is got to be a key or something we can...hmm."

In this conversation, Tom communicated with his partner his perception on how the flashing arrows work in this game environment. Tom also paid attention to the heads-up display (HUD) elements:

Tom: "Maybe... That helped OK so that's what we have to do." Liz: "But he went back on." Tom: "Three times. See how he lost one of his hearts that way." Liz: "Oh OK so we got to do that three times."

Tom: "So there is five of those guys with sort of big guns I think. If I had to guess I would say that's what that (picture of head of five guys on the top of the screen) meant." … Liz: "I think there is something we have to build." Tom: "I don't know it feels like when we kill these guys it makes sense, because we have four these guys on the foot that we need to kill." Liz: "So messed up." Tom: "So let's go over to the other side so maybe we can find them again." Liz: "Another sword." Tom: "Yeah. But we need to find the Sherpa looking people. There."

Tom noticed and talked about several HUD sensory stimuli elements such as the pictures of enemy heads and hearts. As a team they utilized these sensory elements to understand what the goals of the sections are and shape the actions they took in the game world.

Some of the sensory stimuli elements diverted their attention from the right path to the solution. Even though these sensory stimuli elements caused the team to generate wrong solutions, they still instigated conversation between the teammates and allowed them to assume collaborative roles.

> *Liz: "How about those little statues? Can we beat them up?" Tom: "I think they are just pretty but we can certainly try beating them up (after he breaks them) Ah we can beat them up and there is birds. And where did the birds go?" Tom: "Did they come out there at all?" Liz: "I think they run out the ceiling."…Tom realized that there is light hitting on the ground in the center of the room. Tom: "What if you bring out the Ra staff and bring it in the center of the room. Can you do anything?" Liz tries but nothing happens. Liz: "No." … Tom: "How about that staff?" Liz: "Where?" Tom: "You hit the circle and change to that. Can you do anything with that? If you hold square does it tell you where you can use it" Liz: "MmmMmm." Tom: "OK."…Tom: "And there is nothing back up here." Liz: "And that little red light doesn't do anything?" Tom: "I feel like it should, but I think it is just supposed to be something fancy."*

In this example Tom and Liz were trying to identify what actions they needed to take to complete the final piece of the puzzle. They were exploring their environment diligently. Hence every shiny or different colored object was investigated by the team. None of these sensory stimuli elements helped them solve the final piece of the puzzle (they solved it by chance later on). However, these sensory stimuli elements were still essential in promoting conversation and collaboration.

To sum it up, some of feedfront sensory elements such as flashing text and arrows on screen as well as the visuals appearing on the screen helped the team make better decisions on what actions to take in order for them to be able to solve the problem. In addition, some other more subtle visual sensory elements such as different colors and shapes or light shining on a floor also instigated their curiosity. However, this type of stimuli elements did not always lead the team towards a solution, but instigated more conversation that was collaborative in nature..

Clarity of goals and rules.

This game had vague section goals that kept changing based on the gameplay scenario presented to the player. The relatively more open-ended structure of the game combined with unclear goals sometimes confused the players. Although Tom and Liz were able to complete all the tasks, at certain times the completion of the task was unplanned. In Crystal Skull part two, both Tom and Liz knew that the end goal of the section was to win the boss fight, however they were not sure how to damage him. After trying to reach the boss so that they could punch him, they realized that the boss kept moving around the room. At one point, Tom was confused and while he was communicating his confusion to his partner, he walked up to the boss one more time which then resulted with a cut scene that indicated completion of the task.

Tom: "Where is he going now? Now he is in that area. I don’t know what we have to do he is (he walks up to him and cut scene starts.) Oh he was on a glass thing and I went to get close to him but now" Liz: "We ended in a new room."

A similar situation was observed in Raiders of the Ark part one where the team was not clear on the procedural rule to solve the problem. Tom and Liz were trying to figure out how to create a triangle of a beam that a Nazi soldier was aiming at them. With some luck they moved around the reflector dishes in the right locations and solved the problem without knowing how they did it:

> *They accidentally solve the puzzle. Tom: "Oh we got him." Liz: "How?" Tom: "I don't know how."*

Table 34

Reported Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Tom	Liz
Crystal Skull P1	25	23
Crystal Skull P2	20	17
Crystal Skull P3	26	30
Raiders of Ark P1	24	21
Raiders of Ark P2	24	30
Raiders of Ark P3	23	19
Raiders of Ark P4	24	16

In most other cases, they were vaguely aware of the end goal, even though it was Tom who mostly talked about what the possible end goals might be. During this gameplay Tom scored the clarity of the section goals and rules consistently high, while Liz gave some low ranking on some of the sections (Table 34). The observation of their gameplay was also consistent with their scores. Liz was observed to be confused about some of the gameplay rules of the game and was not contributing towards identifying the section goals. However, Tom was more successful in understanding the gameplay rules and he mostly helped his partner through verbally explaining how the game worked. Here are some of the sample excerpts from their conversations that indicate how Tom and Liz communicated about goals and the rules of the game:

Liz: "Looks like I don’t have my gun anymore." Tom: "You don’t have your gun anymore?" Liz: "No" Tom: "Even if you hit the x" Liz: "Yeah I am just punching. Oh X? Tom: "Not X I am sorry the square." Liz: "Maybe I lost it." Liz: "Oh here is my gun. Oh Oh, now I get it. I put my gun away using the circle."

She pressed square and did not realize that she changed her equipment in her hand. Liz: "Did I drop it?"

The team generally performed well on understanding how the operational rules work. When the team was not clear on how the operational rules of the game worked, they resorted to the trial-and-error technique. Since the rules and goals were clearer for Tom, he almost always communicated to his partner his understanding of the rules and the goals. This way they built a common understanding of the problem space. Having a good understanding of the procedural/operational rules helped them solve the puzzles successfully. Here are some of the examples where Tom talks about his understanding of some of the procedural/operational rules:

Tom: "I have a banana. Can I throw the banana at him? (He tries) Sure I can. Did I hit him? No."

Tom: "It might be that if we run out of coins that we die. We might start losing those hearts."

Tom: "You got to be careful. Like if you don't have a torch you can't go in those snake pits."

After touching the spikes while trying to jump, Tom: "Watch out those are spikes and they kill you."

Tom: "I can't get up there. What else can we use? We have the sword and we have a gun. I have a gun! I can shoot them." After trying three times and failing Tom: "Nope I can't *shoot them." Liz: "Anything?" Tom: "So the gun doesn't work, the whip doesn't work. What about, yeah maybe now is when we get the bananas?"*

After watching the cut scene where the beam destroys two Lego mans, Tom: "So don't get hit by the beam."

Tom: "The good thing with the goons is that I think if we hit them three times they die."

Liz: "This one doesn't want to go." Tom: "He is blocking you off. Let me see if I can tie him up." Liz: "He has a gun."

Overall it can be assumed that the slightly unclear goals and constant trial to understand the procedural rules of the game promoted more conversation between the team mates and helped them better develop a common understanding of the problem through forcing them to discuss available actions to solve the problem. In addition, the difference between the team mates' levels of understanding of the game rules created more chances for conversations to take place which then helped them in their problem solving activity.

Within Case 5 – Group 3 (Mike and Dale) Playing Lego Indiana Jones 2

In the session analyzed, Mike and Dale played the game *LEGO Indiana Jones2: The Adventure Continues*. While Mike mentioned that he has played a lot of Lucas Arts games, Dale did not report or observed to be familiar with this game series. This was their second session that they have been playing video games together. During this game, Mike played Indiana Jones and Dale played all the other side characters such as Mac, janitor, Sallah and Marion. Throughout the session, the team, especially Mike, uttered their frustrations and dissatisfactions at various points in the game. The team found certain sections of the game boring and pointed out the design issues that abridged their level of enjoyment of the game.

Starting the gameplay.

During the hub level, the team explored the game world individually and conversed very scarcely. With the help of the feedfront sensory stimuli elements such as flashing text on screen, the team was able to stay on target even though they still explored the hub world more than needed at that point. During this level the team was looking for a banana to give it to a monkey which in return would give a key that would activate a train. While the task was accomplished as a result of collaboration, the lack of conversation between the team mates was noticed. Occasionally Mike sounded like he was thinking out loud rather than having a conversation with his partner.

Mike:" So if I were a banana where would I be?"

Also, sometimes the communication between the team mates seemed to occur without a response. For example when Dale was defining the current state of a problem, Mike chose not to talk about it and just continued what he was doing, i.e. exploring the area.

Dale: "So we need a wrench, key, and a banana." After Mike picks up a banana, Dale: "Now we have got one of those things." Mike: "I have gotten… Well, I played enough Lucas Arts games to know how - to know that of course the monkey has a monkey wrench."

Also, neither of them talked about the flashing text nor read the text out loud when it appeared. However, later on, their conversations indicated that they actually saw the flashing texts but they did not feel the need to talk about it most of the times. Asides from figuring out what they needed to do to complete the level, the team also used the flashing texts to understand the game controls.

Without much conversation Mike handled most of this easy task himself with some help from his partner when he needed. Dale only contributed when Mike asked a question or when Mike was not able to complete an action.

Mike: "How did it say to target?" Dale: "Hold down square"

After Mike fails to put the key in its place, Dale: "Circle." Mike tries a few more times. Dale: "Maybe you have to approach it over on this side?" Mike approaches the lock from a different angle and it works. Mike: "Really that (The fact that he had to approach the key station from another angle) was what was keeping us from doing it?" Dale: "Haha yeah I was thinking the same thing."

As expected, majority of functional roles assumed during the initial hub level was executing individual moves (77%). Signs of collaboration started to show itself towards the end of the task, when Mike had problems executing a move by himself. Both team members rated this level as very easy. After the team quickly completed the hub level (around 2 minutes), they moved on to the next story levels: Crystal Skull and Raiders of the Ark.

In the next levels the team continued to successfully complete the tasks, but it was observed that they did not converse as much as the other teams to share their common understanding of the problem. As the game sometimes frustrated them, they seemed to adopt a “let’s-get-this-over-with” strategy, and completed some of the tasks with minimal collaboration. However, the collaborative nature and challenging parts of the game still forced them to work as a team and brainstorm ideas together.

Collaboration.

As mentioned previously, the team displayed a minimalistic collaboration approach during the story levels of this game. They mostly explored the game world individually. It was also observed that Mike would take the lead and solve the problems without sharing his complete plans. Dale still provided his insights on how to solve the problems, even though sometimes Mike chose to ignore his suggestions.

Mike: "Oh it is the staff. Dale: "Is there another one we theoretically need to make?" Mike is not paying attention to Dale. Mike: "This looks like a trampoline." Dale: "Worst trampoline I have ever seen but."

Dale: "Now if I move over there, is there something you can see while up there?" Mike: "No I didn't see anything. It is got to be something that I can hit while standing on this spot. That's the only spot that works." Dale: "Now is that another button similar to the button that made you flying? On top of this (He is talking about the target) so we can get on top of that?" Mike does not respond to him. Mike: "Maybe I will try hitting it again."

Despite of their lack of interest in the game and their individualistic exploratory gaming style, the team was still able to portray some of the functional roles that exemplify collaboration (Table 35). The team proposed ideas (14%), implemented those ideas (16%), and sometimes discussed their ideas through contesting (1%), agreeing (1%), reasoning (0.2%), rejecting (1%), and modifying (0.5%). However, the majority of their functional roles consisted of executing an individual action (63%).

Table 35

Frequency of Functional Roles Assumed During Indiana Jones 2

		Crystal Skull P1		Crystal Skull P2		Crystal Skull P3		Raiders of Ark P1		Raiders of Ark P2		Raiders of Ark P3		Raiders of Ark P4		Mike Total	Dale Total	Total
		Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale	Mike	Dale			
Execution	N	45	18	12	3	5	4	21	15	39	23	39	24	17	7	178	94	272
	%	71.43	28.57	80	20	55.56	44.44	58.33	41.67	62.9	37.1	61.9	38.1	27.42	11.29	65.4	34.56	63.11
Proposal	N	11	8	3	1	3	1	5	2	2	3	9	6	3	2	36	23	59
	%	57.89	42.11	75	25	75	25	71.43	28.57	40	60	60	40	21.43	14.29	61	38.98	13.69
Implementation	N	10	12	2	2	9	6	3	4	2	3	5	5	6	1	37	33	70
	%	45.45	54.55	50	50	60	40	42.86	57.14	40	60	50	50	37.5	6.25	52.9	47.14	16.24
Modification	N	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	2
	%	100	0	0	0	0	0	0	100	0	0	0	0	0	0	50	50	0.46
Contestation	N	4	0	0	1	0	0	1	0	0	0	0	0	0	0	5	1	6
	%	100	0	0	100	0	0	100	0	0	0	0	0	0	0	83.3	16.67	1.39
Rejection	N	0	0	0	0	0	0	0	0	0	0	3	1	0	0	3	1	4
	%	0	0	0	0	0	0	0	0	0	0	75	25	0	0	75	25	0.93
Acceptance	N	1	0	0	0	0	0	1	0	1	1	2	0	0	0	5	1	6
	%	50	0	0	0	0	0	100	0	50	50	100	0	0	0	83.3	16.67	1.39
Reasoning	N	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	%	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0.23
Testing	N	0	1	0	0	0	0	0	0	0	1	3	1	1	0	4	3	7
	%	0	100	0	0	0	0	0	0	0	100	75	25	100	0	57.1	42.86	1.62
Explanation	N	2	1	0	0	0	0	0	0	0	0	1	0	0	0	3	1	4
	%	66.67	33.33	0	0	0	0	0	0	0	0	100	0	0	0	75	25	0.93
Total	N	75	40	17	7	17	11	31	22	44	31	62	37	27	10	273	158	431
	%	65.22	34.78	70.83	29.17	60.71	39.29	58.49	41.51	58.67	41.33	86.11	51.39	37.5	13.89	63.3	36.66	100

Joint problem space.

As Mike and Dale shared the same game environment and worked on the same puzzles together, they necessarily built a common understand of the problem space. However, they did not always have two-way conversations, or complete each other's thoughts/ideas to reach a common solution. Although Dale contributed towards the solution making as much as he can, Mike was observed to be the lead in solving the problems during this gameplay.

Mike: "Green square means we can put things one it." Mike: "Umm there is a target up there." (Identifying problem state) *Dale: "Where is that?" Mike: Umm up here there is a target."*

They try to interact with the box that just opened up, but they can't, so they kept exploring the area. Dale shoots at a target. Mike: "What the heck? What did you shoot?" Dale: "The top there (target) which opened that box up, but." (Problem state identified) *Mike: "Why do we care?" Dale: "That I do not have the answer to."* (They failed to realize the association between this action and the next problem state.)…*Dale: "Now can we lift this up to put it on the other green block?* (Possible action identified)*And that have some benefit?" Mike smashes the crate that Dale was pointing to. Mike: "No I cleared of this." Dale: "Just great." Mike: "Violence is cool. That one, that looks like the other one that I carried off."*

Mike: "OK. It is telling us to stand here (looking at the arrows flashing on top of the lighted area on the floor)." (Problem state identified) *Mike: "Oh it is the staff (Now realizing what the thing he picked up from the box earlier was)." Dale: "Is there another one we theoretically need to make?" Mike is not paying attention to Dale. Mike: "This looks like a trampoline."* (Problem state identified) *Dale: "Worst trampoline I have ever* *seen but." Mike: "OK we need something to reflect.* (Problem state and possible action identified) *Oh (He sees the explosives on top of the crates on the right side.) I see explosives."* (Problem state identified)

Mike tries to reflect the light beam on the explosives to blow them up. Dale: "Yeah, so can you raise it up to blow up that area?" (Possible action identified) *Mike: "I don't think I can make it go up." While he was moving the beam around the room it hits the case that the robot is hiding and blows it up. Mike: "Oh I can laser that."* (Possible action is identified)

Mike tries to find something that he can use the light beam on while Dale is moving around to explore it. Mike: "OK something is getting blasted." (Problem state identified) Dale: "Is there anything on this side of the room? No." Mike: "Maybe I can move." (Possible action identified) *Mike: "OK it is got to be something I can see from this angle."* (Problem state identified) *Mike: "Oh there is a button."* (Problem state identified) *Mike steps on it. Mike: "I am going to send you flying to the air"* (Possible action identified) *Then he gets off and Dale steps on the button. Mike: "You send me flying to the air." Dale: "Now if I move over there, is there something you can see while up there?" Mike: "No I didn't see anything. It is got to be something that I can hit while standing on this spot. That's the only spot that works."* (Problem state identified) *Dale: "Now is that another button similar to the button that made you flying? On top of this (He is talking about the target) so we can get on top of that?"* (Problem state and possible action identified)

Mike does not respond to him. Mike: "Maybe I will try hitting it again." Mikes sees arrows flashing on the bottle. Mike: "Oh maybe I should get that." Mike: "Can you shoot *the stuff up there?"* (Possible action identified) *Dales shoots but nothing happens. Mike goes next to the robot and starts pressing several buttons and one of them build the moving Lego blocks next to the robot. Mike: "Oh (inaudible) One arm at least (he still doesn't realize he has to build the moving Lego parts) Do you have the second arm?" Dale: "I believe I didn't pick anything up." Mike goes next to a pile and presses couple of buttons until he gets it right. Mike: "Oh wait it is the piles. They are arm piles."* (Problem state identified) *They build the robot. Mike: "Do you have one (Staff of Ra) too?"* (Problem state identified) *Dale: "I don't think. How did you activate yours?" Mike: "Can you go back? Is there another one in that place you shot?"* (Problem state and possible action identified) *Dale picks one up: "Yes yes there is."*

In this conversation it was appeared that Mike was speaking to himself as if he was thinking out-loud rather than talking to his partner. He ignored Dale's comments a few times and continued his thinking out-loud process. Mike sometimes shared information that helped Dale to comprehend Mike's understanding of the problem. In general the team (mostly Mike) was able to verbalize their identification of the problem states and possible actions. At one point their conversation displayed how they failed to understand the associations (opening the box would give them access to a Staff of Ra) between problem states (there was Staff of Ra in the box) and actions (opening a box). In general the team did not converse about the association between actions and problem states.

Mike is standing on the place to put the reflector dish. Mike: "Is that a switch or something?" (Problem state identified)*Dale: "I don't know. Looks like it should be." Dale: "Oh there is the yellow thing (small reflector dish) over on this side."* (Problem state identified) *Mike: "It won't let me face in that direction."* (Problem state identified)

Dale: "I see. I wonder if there is anything that is there for." Mike: "There is got to be something with this (reflector dish slot)." (Problem state identified) *Mike: "Really we can't slide the statue again, can we?"* (Problem state identified) *Dale: "Not to my knowledge. Unless there is some way to pull it on."* (Possible action identified) *Mike: "This thing looks like it should move but it doesn't."* (Problem state identified) *Dale: "It is not on the track (checkered) thing."* (Problem state identified) *Dale: "How about that circle thing over here. Can you aim it on that at all?"* (Problem state and possible action identified) *Mike: "No" Mike: "There is got to be something you need to do near me when I do this (reflecting light beam around the room)"* (Problem state identified) *Mike: "What is the thing on the side do?" Dale: "This?" Mike: Yes." Dale tires to interact with it. Dale: "It doesn't give me the option to interact with, I don't think." Mike switches to his whip. Dale: "Yeah can you lasso that switch up there maybe?"* (Possible action identified) *Mike: "Nope." While he is moving around the crosshair it changes color and Mike realizes there is one more thing he can interact with. Mike: "But this thing, I can do this thing."* (Possible action identified)

This conversation presents one of the rare examples of coming up with a solution together. The teammates took turns in identifying problem states and possible actions. Both teammates were observed to put almost equal amount of effort during this collaborative problems solving activity. They identified the problem states and possible actions through using the question and answer technique which in return lead them towards converging on a solution. Another example that has hints of joint problem solving is presented below.

Mike: "Umm spear. (Problem state identified) *What can I hit with the spear?* (Possible action identified) *Umm the red thing?"* (Association between possible action and problem state identified) *He tries to aim on the red thing but the crosshair doesn't change color. Mike: "No." Mike: "What looks like it needs to be speared?"* (Trying to next problem state) *Dale: "Umm I don't know. Something over the other side maybe? Up to your right maybe?"* (Problem state identified) *Mike aims the spear and the crosshair changes colors and he throws the spear. Dale: "Those looks like things that can be speared."* (Problem state identified) *Mike: "Are there other spears up here?" He climbs up and realizes there aren't any other spears up there. Mike: "No it is just that one."* (Problem state identified) *Dale: "Maybe there is no other place to throw it then. Can you use your lasso to jump up to one of those?"* (Problem state and possible action identified) *Mike: "I keep forgetting about that thing." Mike tries the lasso but it doesn't work. Mike: "That's not a spear is that? What the blue thing? No that's death. Umm can we get more spears?"* (Problem state identified) *Mike: "What is on the other side?" He walks up to the other side of the room. Mike: "Oh maybe something. We need the torch."* (Problem state identified) *Mike picks up a torch and walks through the snake pit. When he reaches to the lever he pulls it down. Dale: "What did that do?" Mike: "Spear."* (Problem state identified) *Dale: "Good." Mike throws the second spear and they both try to jump on the spear. Mike: "Ok yeah so we can't go up." Mike: "We can't jump, but we can pull up that."* (Problem state and possible action identified) *Mike pulls the second lever which brings out a platform to jump on. Dale: "Now it makes sense." Mike: "You are a few pixels of then (complaining about the game design). OK" Mike: "Maybe I can't get up there because you can jump higher."* (Problem state identified) *After Dale reaches the spear that is attached to the statue, it lowers down dragging the other statue with it. Mike: "Stay there." Then he* *jumps on the statue as well which brings down the other statue completely and creates an opening for them to exit.*

In this case Mike started sharing his thought process with identifying the elements of the problem state. Dale, then, pitched in and helped him identify some of the other states in the discussed problem. After this small instance of collaboratively solving a section of the puzzle together, mainly Mike solved the rest of the puzzle and Dale only followed Mike's commends. It is interesting here to see that they perform actions such as pulling a lever or throwing spears without mentioning how these actions will help them move to the next problem states. Perhaps the nature of video gaming does not always require players to discuss their actions ahead of time before they move from one problem state to another. For example Mike threw all those spears without any mention of how they could be used later on. Mike asked Dale to jump from spear to spear so he could reach the statue without any mention of why he should perform this action. These associations between problem states and actions went unstated during this session.

As these examples showcase, overall Mike and Dale were not able to construct a strong shared problem space during this session. Although they individual identified problem states and sometimes shared them with each other, they were still not successful at sharing their understanding of the connections between possible actions and states. Overall, Mike solved the puzzles and asked for Dale's help when he needed it. If and when Mike could not solve the puzzle himself then they mostly explored the game world individually and sometimes brainstormed ideas until one of them came up with a solution.

Influence of game elements on collaborative problem solving.

Challenge.

Mike perceived this game more challenging than Dale for the most of the times and Dale only found first, second and the sixth sections of the game somewhat challenging (Table 37). Unfortunately the scoring of the last section by Dale was missing. Mike was predominant in almost all of the problem solving activities encountered during this session. Therefore he possibly perceived the game harder than his partner. In the first section Dale reported higher perceived levels of challenge than Mike. This might have been due to the fact that Dale had harder time understanding game mechanics as both team mates were still learning how to play the game.

Table 36

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Crystal Skull P1	Mike	5	45	11	10	1	4	0	1	1	0	2
	Dale	11	18	8	12	0	0	0	0	0	1	1
Crystal Skull P2	Mike	11	12	3	2	0	0	0	0	0	0	0
	Dale	9	3	1	2	0	1	0	0	0	0	0
Crystal Skull P3	Mike	9	5	3	9	0	0	0	0	0	0	0
	Dale	6	4	1	6	0	0	0	0	0	0	0
Raiders of Ark P1	Mike	8	21	5	3	0	1	0	1	0	0	0
	Dale	6	15	2	4	1	0	0	0	0	0	0
Raiders of Ark P2	Mike	9	39	2	2	0	0	0	1	0	0	0
	Dale	5	23	3	3	0	0	0	1	0	1	0
Raiders of Ark P3	Mike	9	39	9	5	0	0	3	2	0	3	1
	Dale	11	24	6	5	0	0	1	0	0	1	0
Raiders of Ark P4	Mike	10	17	3	6	0	0	0	0	0	1	0
	Dale	.	7	2	1	0	0	0	0	0	0	0

Both team mates put equal amount of effort to try to explore the game world to identify possible states and actions that the problem space brought about during this section. Even though they were exploring the game world on their own and identifying possible actions individually, they still had to communicate their solutions to their partners. For example when they were trying to figure out how to get Mac up to the crates during Crystal Skull part 1, they both presented their own solutions and shared their ideas with each other:

> *Dale: "I wonder like where you have the whip and I am supposed to go a different route?" Mike: "Maybe I can knock something down to help you out." After seeing a flashing text, Mike: "Oh I can push objects." Mike pushes the box down the crates and moving Lego parts falls on the floor. Another text appears on the screen telling them that they can build Lego bricks. Dale builds parts of the staircase without realizing when he presses some buttons on the controller when he was next to the moving Lego pieces. Then Mike says: "Build yourself a staircase", but Dale does not react to what Mike says and Mike comes down to do it himself. Dale has not realized that Mike built a ladder for him to be able to climb up the crates. Dale: "So if we go back up here around the other way..." Mike: "I think I built a ladder over here. Yeah you can climb up. Jump up bunch of times."*

As can be seen in Table 37, during this section of the game, the team members assumed more variety of functional roles and proposed the most ideas that lead them to successful completion of the section. The challenge of trying to learn the game during this session resulted in more conversation about the possible states and action in the game, but did not promoted a healthy way of solving the problems together, since both team mates were overwhelmed with the game mechanics.

In the later sections, Mike generally took the lead and solved most of the puzzles himself, causing Dale to put little effort into solving the puzzles together. However, when it was observed that Mike was having a difficult time to solve the puzzle, Dale was inputting more ideas towards the solution. For example in Raiders of Ark part 3, both team mates were struggling to figure out the purpose of a reflector dish on a slot.

> *Mike is standing on the place to put the reflector dish. Mike: "Is that a switch or something?" Dale: "I don't know. Looks like it should be." Dale: "Oh there is the yellow thing (small reflector dish) over on this side." Mike: "It won't let me face in that direction." Dale: "I see." Dale: "I wonder if there is anything that is there for." Mike: "There is got to be something with this (reflector dish slot)." Mike: "Really we can't slide the statue again, can we?" Dale: "Not to my knowledge. Unless there is some way to pull it on." Mike: "This thing looks like it should move but it doesn't." Dale: "It is not on the track (checkered) thing." Dale: "How about that circle thing over here. Can you aim it on that at all?" Mike: "No" Mike: "There is got to be something you need to do near me when I do this (reflecting light beam around the room)" Mike: "What is the thing on the side do?" Dale: "This?" Mike: Yes." Dale tires to interact with it. Dale: "It doesn't give me the option to interact with, I don't think." Dale: "Yeah can you lasso that switch up there maybe?" Mike: "Nope." Mike: "But this thing, I can do this thing." While he is moving around the crosshair it changes color and Mike realizes there is one more thing he can interact with.*

As can be seen from this example, the increased challenge level for this team resulted with a more balanced contribution towards finding a solution to the problem faced. Even though the team was not clear about the consequences of their actions, they were successful at identifying possible actions together and assuming variety of functional roles. Through adapting various roles that constituted their collaborative approach and through question and answer they were able to converge on a solution for the problem faced during this section.

To sum it up, the increased challenge levels due to the complexity of the problem encouraged this team to work together, whereas the challenge that was due to their unfamiliarity with the gameplay did not helped them in developing a shared understanding of the problem and solving the problem collaboratively. Also, it is important to note that there was still very little collaboration.

Sensory stimuli elements.

Initially in the game, Mike and Dale did not pay a lot of attention to the profusely provided feedfront sensory stimuli elements. Instead the team chose to utilize a trial-and-error technique to overcome the puzzles. They pressed every possible button on the controller when they wanted to interact with an object in the game until something right happened. They solved some of the challenges in the game through this exploratory strategy rather than trying to make sense of the sensory stimuli elements. For example since they did not pay attention to the flashing text on the bottom of the screen, they did not realize that they can build objects by interacting with moving Lego pieces, until Mike discovered it by chance when they first encountered one. However, when they encountered a pile of moving Lego pieces for the second time, they still did not have the understanding that they need to use those pieces to build something, until again Mike by chance started pressing a button when he was close to a pile.

Later in the game the team learned how certain sensory stimuli elements were necessary to utilize to solve the problems successfully. They started paying more attention to the flashing text appearing on the bottom of the screen, arrows appearing on top of the interact-able objects, certain colors and shapes, as well as objects with movement. Their increased awareness of the sensory stimuli elements slightly facilitated their collaborative process and resulted with display of some of the functional roles. However, since they did not communicate extensively with each other about the sensory stimuli elements it was not always clear whether a functional role was a result of encountering with a sensory stimuli element. A list of the sensory stimuli elements and the corresponding functional roles that were observed during this game are presented in Table 36.

Table 37

Sensory Stimuli Events in Indiana Jones

Sensory Stimuli Type		Functional Role Triggered[a]	Example Participant Reaction
Visual	Flashing Text	A-E	Mike: "Oh I can push objects."
	Color	A-E	Mike: "Green square means we can put things one it."
	Flashing Arrows	A-P A-I B-I	Mike: "OK. It is telling us to stand here.(looking at the arrows flashing on top of the lighted area on the floor)"
	Flashing Arrows	A-E	Mikes sees arrows flashing on the bottle Mike: "Oh maybe I should get that."
	Flashing Arrows	B-E	Dale: "It wants us to go this way."
	Moving Lego Pieces	A-P A-I B-I	Mike: "Hey this looks like something we can build."
	Sparkling Objects	A-E	Mike: "What is in here? It is sparkling, must be important."
	Controller Signs	B-P	Dale: "This has a green triangle next to it. It is going to be important."
	Color	A-P B-R	Mike: "This thing looks like it should move but it doesn't." Dale: "It is not on the track (checkered) thing."

Notes. [a]A: Mike B:Dale / E:Execute P:Propose A:Accept I:Implement M:Modify T:Test S:Reason R:Reject C:Contest X:Explain

The team members took advantage of the sensory stimuli elements during their individual problem solving activity. It was observed that Mike was conversant mostly about how sensory stimuli elements affected his way of thinking and playing the game. He was able to identify the possible actions he could perform to solve the problem after encountering sensory stimuli elements.

Mike: "Oh I can push objects." (After seeing the flashing text on screen.)

Mike: "Green square means we can put things on it."

Mike: "OK. It is telling us to stand here (looking at the arrows flashing on top of the lighted area on the floor)."

They are not paying attention to the flashing text instructions rather Mike is pressing every button until one of them works.

It was observed that the team did not pay attention to most of the on screen flashing text sensory elements serving as a feedfront mechanism. However, they seemed to acknowledge more subtle sensory elements such as flashing arrows, sparkling objects, or distinctive color/shapes. These sensory elements helped the team in identifying problem states and started conversations between the partners.

Dale: "It wants us to go this way." (After seeing a green flashing arrow)

Mike: "What is in here? It is sparkling, must be important."

Mike: "There is something over here." Dale: "This has a green triangle next to it. It is going to be important."

Mike: "Does that red thing do anything?" Dale: "Which red thing are you referring to?"

Mike gets over there and tries to interact with the red puller. Mike: "Looks like not."

Unfortunately, the scarceness of conversation between the teammates limited the way we can observe how sensory stimuli elements influenced the collaborative problem solving process for this team. From the very minimal conversation that was observed during this session, it can be concluded that the sensory stimuli elements had a positive influence on starting conversations between the team members and they helped players to solve the problems individually, if not somewhat collaboratively. However, it should also be noted that the sensory elements encountered in this game did not promote a more effective way of collaborative problem solving for this team. Overall, the team did not develop a strong joint understanding of the problems.

Clarity of rules and goals.

Asides from the frustrations with some of the rules of the game that was observed during this session, the team appeared to be unsure about goals and the rules most of the times. Even though Dale reported that the goals and rules of the game were pretty clear to him, Mike's scoring for this session represented what was observed in the gameplay more accurately (Table 38).

Table 38

Reported Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Mike	Dale
Crystal Skull P1	15	23
Crystal Skull P2	12	24
Crystal Skull P3	11	24
Raiders of Ark P1	13	26
Raiders of Ark P2	8	25
Raiders of Ark P3	6	20
Raiders of Ark P4	9	.

Clarity of the game goals and the rules influence the way team members identify possible actions and their current states in the problem space. It was observed that the team did not have a clear understanding of the game goals, or even the consequences of some of the actions they performed. This resulted with them to take resort in trial-and-error strategy to overcome some of the problems they faced. The team performed any action that they could possibly take even without knowing what the result of that action was going to be.

Mike: "What? OK" He buys the Sherpa Brawler without realizing. Mike: "I have no idea what I just did." Dale: "You added another guy to our merry band."

Mike: "Um what is this?" Dale: "Pull the switch to make something happen (reading the text appeared on screen)." Mike: "Umm I think we need to go swinging." The bandit keeps throwing bombs at them. Mike: "Ok I am starting to dislike that guy." Dale: "Ok Now I am up here. Probably has some value." The team is still not sure how climbing up will benefit them in progressing towards the end goal. Dale: "I have the sense that one of us should distract him while the other one actually does something." As Dale approaches the bandit, the bandit leaves his position. Dale: "He got to leave this area. It is going to be good right." Mike: "He jumped down." Dale: "Yeah." Mike: "Because you knocked him." The team had an understanding of the fact that they need to get to the bandit but they were not sure what that will result with.

Mike pulls down a lever without knowing what he just did. Mike: "Oh I am not sure why that happened." Dale: "Excellent." Mike gets up to the place to put the reflector dish. Mike: "Is that a switch or something?" Dale: "I don't know. Looks like it should be." They try to interact with the switch by pressing all the buttons on the controller.

This attitude eventually helped them solve the puzzles of the game even if it is without having a full understanding of it sometimes. Even though as gameplay progressed they started to have a better understanding of how the game mechanics worked and what kind of end goal they were trying to accomplish, it was observed that the game rules were still not very clear to the team. Since the game introduced a different environment and game objects for every section, they had to learn the rules associated with the new game objects and adjust to the new environment every time. For example while at the beginning they could move away from each other and the screen would just split up for them, in later sections they learnt that they could not always move further away from each other. Other examples of this phenomenon occurred when they encountered monkeys, camels, snakes, bandits with machine guns, and ninja bandits etc.

Although this confused state allowed the teammates to exchange their understandings of the game rules and goals, it did not help the team to collaboratively solve the problems in an effective way. Even though team mates developed a shared understanding of the problem through communicating, the solutions sometimes came as a result of either individual efforts or by some luck.

Within Game - Across Group: Indiana Jones 2 and Collaborative Problem Solving

Indiana Jones 2: The Adventure Continues provides a variety of platforms for the players to collaboratively solve the problems. While some parts of the game focus on solely puzzle solving, some parts focuses strictly on fighting, and on rare occasions fighting and puzzles are combined. Therefore this game can cater to players with various backgrounds and interests. During this research project only two groups played this game. The sections of the games played by each group are presented in Table 39. Both Tom and Liz, and Mike and Dale played the game for the length of a one research session. While Tom and Liz seemed to enjoy the game and were observed to be fully engaged with it, Mike and Dale expressed their displeasure and reported that they felt bored during some of the sections.

Table 39

Indiana Jones 2 Completed Sections for Each Group

Groups	Completed Sections	Number of Sessions
Group 1	Kingdom of the Crystal Skull Part 1: Hub World Hanger Havoc Raiders of the Lost Ark: Hub World Raven Rescue Market Mayhem Map Room Mystery	1 (Third Session)
Group 3	Kingdom of the Crystal Skull Part 1: Hub World Hanger Havoc Raiders of the Lost Ark: Hub World Raven Rescue Market Mayhem Map Room Mystery	1 (Second Session)

Overall, group one, Tom and Liz, displayed a better collaborative problem solving than group three. As one of the members of group three, Mike, did not enjoy playing this game his approach to solving the problems became more individualistic to quickly get over with it. Mike and Dale did not communicate and collaborate as much as Tom and Liz. Group one was observed to be confused at times during this game play, but they collaboratively built a joint understanding of the problems and converged on solutions. Specific influence of game attributes on collaborative problem solving is discussed in the following sections:

Challenge.

Through using a combination of action and puzzle focused sections, this game provided various challenges. Players were challenged both by complex puzzles and fight scenes that required them to have quick reaction time as well as good hand eye coordination. Overall group three found this game more challenging, but both teams were observed to react to the challenges in a similar fashion. Group three reported somewhat consistent levels of challenge and group one's perceived levels of challenge fluctuated more (Table 40).

Table 40

Reported Total Challenge Levels of Each Group

	Group 1 Total Challenge Rating	Group 3 Total Challenge Rating
Crystal Skull P1	11	16
Crystal Skull P2	13	20
Crystal Skull P3	3	15
Raiders of Ark P1	15	14
Raiders of Ark P2	11	14
Raiders of Ark P3	15	20
Raiders of Ark P4	17	--

Group one was not as collaborative when faced with difficult game play combined with a difficult task. When faced with small intricate tasks as part of a complex puzzle they tended to display more functional roles. Similarly, group three's collaborative problem solving was at the peak when they faced a difficult puzzle. Being challenged by the unfamiliar game play mechanics did not promote Mike and Dale to work together.

Sensory stimuli elements.

Both groups managed to utilize the sensory stimuli elements that they were bombarded with during this game. However they differed in their level and style of utilization of sensory stimuli elements during the collaborative problem solving process. Tom and Liz acknowledged and used almost all of the sensory stimuli elements for their advantage. Their use of sensory stimuli was evident in their conversations. They shared their understanding of the sensory stimuli elements with each other and incorporated them during identifying problem states, actions, and associations between states and actions. On the other hand, for most of the sensory stimuli elements, Mike and Dale did not overtly express their acknowledgement, even though some of their actions indicated that they were incorporating those sensory stimuli elements in their individual problem solving. The most commonly used sensory stimuli elements by both teams were flashing arrows and subtle clues such as a unique color or a shape of an object. Specific type and level of sensory stimuli element utilization for each group is provided in the Table 41.

Table 41

Type and level of sensory stimuli element utilization for each group

Type of Sensory Stimuli Element	Level of Utilization Based on Discourse	
	Group 1	Group 3
Flashing text	High	Low
Flashing arrows	High	Medium
Moving Lego pieces	High	Low
Unique color and shape of objects that can be interacted	High	Medium
HUD	Low	None
Crosshair	Medium	None
Ticking Noise	Low	None
Controller Signs	Low	Low

Clarity of goals and rules.

This game provided poorly presented goals that differed based on sections. Both groups were observed to be vaguely aware of the section goals. However, in group one, Tom was more observant of the goals and occasionally communicated his understanding of the game goals with Liz. On the other hand Mike and Dale did not talk about the game goals during this session. Procedural game rules also were observed to be confusing at times for each of the groups. The confusion about the procedural and operational rules promoted more conversation between the team mates for group one. Both groups solve the problems with trial-and-error method along with some lucky actions. Overall the group one was more successful at developing a shared understanding of the problem and converging on a solution together due to the unclear goals and rules of this game. The obscurity of the goals and rules caused second group to solve the problems individually but then have a conversation about them afterwards.

Chapter 5 Summary

This chapter provided the results of within case analysis for two first level cases: Within Case 4 – Group 1, and Within Case 5 – Group 3. Each section presented detailed information about the player interactions and discourse that took place during the gameplay sessions. The influence of game design attributes was discussed at the individual group and session levels. At the end of the chapter, results across all two groups were collapsed and presented in the within game across group section to identify the similarities and differences in the associations between game design attributes and collaborative problem solving across groups with different players and dynamics.

Chapter 6 – Borderlands

This chapter includes the analysis of two first-level cases that consist of group one, and four, as well as a within-game across-group analysis of *Borderlands*. During this chapter each group's gameplay, conversations, and interactions are thoroughly analyzed to examine the potential relationships between the game attributes and collaborative problem solving process. The results are presented under the following two sections: Within Case 6 – Group 1 (Tom and Liz), and Within Case 7 – Group 3 (Mike and Dan).

Within Case 6 – Group 1 (Tom and Liz) Playing Borderlands

During their fourth session together, Tom and Liz played *Borderlands*, an action RPG/first person shooter game. While Liz selected the only female character in the game, Lilith the Siren, Tom selected to play as the Brick, a muscular Berserker who is good at melee combat. Both players were inexperienced in playing first person shooter games which generally contain action packed combat scene that require players to maneuver quickly in the game environment while trying to kill the enemies. This inexperience was portrayed very obviously by both team members as they struggled to aim at the fast moving enemies correctly while moving around in the game world themselves. Even though both team members started at a similar level of inexperience, the learning curve for Tom was quicker than Liz. After couple of missions he quickly adapted to the fast pace of the game and became better at the combat scenes and understanding the game rules. While Liz slowly improved her gameplay, she was still observed to be struggling at aiming, shooting, and moving around the game world throughout this session. Even if it was difficult for them to play this game, they completed five missions in an hour and thirty minutes session.

Starting the gameplay.

After the two mercenaries got off a bus around the town of Fyrestone they began their adventure. The team spent their initial a few minutes to understand the bars and the indictor displays that were presented on the screen. As usual Tom took the lead and explained to Liz the purpose of the indicators and his understanding of this new game. They both read out loud any instruction that appeared on their screen as a text which helped them to share their understanding of the gameplay. Throughout the game Liz seemed confused and not able to understand the operational rules as well as Tom did. Overall the team displayed a friendly and harmonious teamwork, but due to the fact that Liz was having difficulty playing this game it was observed that Tom was the lead role during this collaborative problem solving effort.

Collaborative problem solving.

This open-ended role playing game required the team to undertake a series of missions (i.e. specific problem tasks) along with some overarching problem tasks. Some of the overarching problems that the team entangled during this gameplay included “trying to come up with a combat strategy appropriate for the situation that they were in”, “managing and allocating recourses in a way that would enhance their combat strategies”, and “identifying the locations of the mission”. While in general Tom embarked on the leader role and expressed his ideas various times during most of these overarching problem tasks, Liz assumed a more passive role and followed Tom’s lead. It was also observed that Liz was mostly dependent on Tom to figure out the game rules or the necessary actions.

Tom: "So let's back up a minute? And like hide?" Liz: "Do I need to go get some more lives? I am running out.” Tom: "Yeah." Liz: "So I have to get out of here?" Tom: "I don't know what else we can... Ok so it is good to know that square is the interact button, so we *can sort of pick up anything with that." Liz goes to a New-U Station mistakenly thinking that she can improve her health. Liz: "Wait how do I get lives?" I thought... I don't know." Tom: "I know if we die then we come back to those spawn points but I bet there is probably health packs or med packs or something like that that will restore our lives." Liz: "OK I need to get back."*

Tom: "Got him. But there is another one shooting at us from somewhere. And I am heavily hurt. Where are they shooting from?" Liz: "No idea." Tom: "Behind us." Liz: "And I have no ammo." Tom: "I am also out of ammo on both guns." Liz: "Where is he?" Tom: "Where I am. You see the researcher group 1 thing (user name appearing on screen). That's how you can tell." Liz: "Yeah."

Tom: "If you hold the square down. (Liz's character says out of ammo) That's OK you just saved my life." Liz: "So I have to be next to you?" Tom: "If we are next to each other and hold the square down then we can save each other."

Through all the looting someone is shooting at Liz and she is about to dies but none of them realizes it even though the screaming of character and her life indicator going down and red banners appearing on screen. Finally Tom realizes that Liz is being shot, Tom: "And he is shooting at us. To the left."

Tom: "We got them. (He realizes there are still more bandits even though they reached the necessary number for the mission) Oh can you get out of there?" Liz: "Oh." Tom: "Because we killed a bunch of bandits but there is a bunch more." Liz: "Where are you?" Tom: "I am back at the entrance." (She sees a bandit and thinks that it's her partner) Liz: "Oh there you are." Tom: "Yeah. And I will try and cover you if you can come out, but... I would, no that's not me." Liz: "Oh." Tom: "That's a bandit that you are running at."

Liz’s confusion about game rules and play tactics continued for the rest of the session, but this did not influence their success at completing the given missions. They learnt how to work as a team and Tom portrayed an extra effort during combat scenes to make sure that both of them stayed alive. As they progressed in the game their missions included increased number of enemies that are harder to kill. During one instance, Tom and Liz failed at clearing the town entrance off enemies after several tries of going into combat without a plan. This frustrated Tom but also forced the team to come up with a plan and work somewhat more as a team rather than individuals jumping in the middle of battle:

> *Tom: "I think we need to stay and shoot at them, because I can't go out there and save you." Liz: "That's fine. I will just shoot them until they die." Tom: "But let's try and work together. Like if you can sort of guard the gates, I am going to go buy more ammo." Liz: "So shoot at them?" Tom: "So don't shoot at them unless they come inside and I am going to buy more ammo." Liz: "OK."*

This instance demonstrated Tom’s position as the leader of this dyad and Liz’s position as the follower. An examination of their functional roles observed during this session also revealed a similar pattern. As can be seen in Table 42, Tom (85%) proposed more ideas than Liz (15%) that constitutes total of 19% of their overall observed functional roles. While there was still a lot of individual action taking (50% of all the roles observed), both players managed to work as team and converge on solutions for the problem tasks.

Table 42

Frequency of Functional Roles Assumed During Borderlands

		Mission 1		Mission 2		Mission 3		Mission 4		Mission 5		Tom Total	Liz Total	Total
		Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz	Tom	Liz			
Execution	N	31	20	16	9	8	6	16	8	25	21	96	64	160
	%	60.78	39.22	64	36	57.14	42.86	66.67	33.33	54.35	45.65	60	40	50
Proposal	N	18	4	3	0	6	2	11	1	13	2	51	9	60
	%	81.82	18.18	100	0	75	25	91.67	8.33	86.67	13.33	85	15	18.75
Implementation	N	13	9	2	2	7	5	5	3	6	9	33	28	61
	%	59.09	40.91	50	50	58.33	41.67	62.5	37.5	40	60	54.1	45.9	19.06
Modification	N	0	0	0	0	1	0	0	0	1	0	2	0	2
	%	0	0	0	0	100	0	0	0	100	0	100	0	0.63
Contestation	N	0	1	0	0	0	0	1	1	3	2	4	4	8
	%	0	100	0	0	0	0	50	50	60	40	50	50	2.5
Rejection	N	1	0	0	0	1	0	0	0	0	0	2	0	2
	%	100	0	0	0	100	0	0	0	0	0	100	0	0.63
Acceptance	N	0	1	0	0	0	2	0	1	0	1	0	5	5
	%	0	100			0	100	0	100	0	100	0	100	1.56
Reasoning	N	0	0	0	0	0	0	2	0	3	0	5	0	5
	%	0	0	0	0	0	0	100	0	100	0	100	0	1.56
Testing	N	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0
Explanation	N	9	0	2	0	2	0	3	0	1	0	17	0	17
	%	100	0	100	0	100	0	100	0	100	0	100	0	5.31
Total	N	72	35	23	11	25	15	38	14	52	35	210	110	320
	%	67.29	32.71	67.65	32.35	62.5	37.5	73.08	26.92	59.77	40.23	65.63	34.38	100

Their discourse indicated that Tom and Liz were able to build a joint problem space through communicating about the problem states and possible actions that they could take. While identifying their problem states, they frequently talked about their situation in the game world through identifying what game objects available for them, what they can purchase or obtain, where they are located, or where they need to be. More specifically, they talked about their level of health, or ammo and what they need as well as locating the flashing diamond on the map to understand where they need to go. In addition, before and during most of the missions Tom requested that they should check their inventory/backpack and purchase new equipment before they proceed to take on the challenges of the game. During these extended times (around 4-5 minutes) that they spent on discussing their state, they also talked about their mission goals which allowed them to develop a common understanding of the goals. Even though the conversations between them indicated that Tom had a better handle at understanding what was going on in the game environment, his willingness in sharing his knowledge with Liz allowed this team to develop a shared understanding of the problem.

> *Tom: "Vladafs are out of ammo. Tediores are out of ammo.* (Problem state identified) *Wait a minute umm I wonder if we. There is got to be a way to get into the inventory maybe we can hit start.* (Possible action identified) *That's not it." Liz: "Oh to see how much supply we have left?"* (Association between an action and problem state identified) *Tom: "Well I am just thinking like it would make sense if. Are you totally out of ammo? Or do you have?"* (Inquiring to gain information about problem state) *Liz: "I just restocked." Tom: "You just restocked. OK." Tom: "Oh wait and here is more stuff."* (Problem state identified) *Liz: "Yeah you can take that."* (Possible action identified) *After also taking the health pack on the ground without knowing what he took Tom reads the*

text on the screen explaining what he just obtained. Tom: "Minor insta-healt vial and some combat rifle bullets. Oh good so my Vladaf I think should have." (Problem state identified) *Liz: "Oh I am out of ammo in one of them."* (Problem state identified – contradicting her earlier statement about being restocked) *Claptrap keeps asking them to come next to him. Tom: "There you go. And what's his face (Claptrap), wants us to go over somewhere else"* (Problem state identified) *Liz: "Go over there." [At the same time with Tom] Tom: "But I don't know where he is." Liz: "Right there in front of us."* (Problem state identified) *Tom: "Oh."*

In this example, Tom and Liz were trying to manage their inventory of ammo. They discussed about the states of the problem and what possible actions that they can take. While Tom started the conversation about the problem state (their need for ammo), Liz contributed and helped Tom locate ammo that was lying on the floor.

Tom and Liz talked about their mission in detail. They generally restated the mission goals and discussed strategies before they took any action. Even though mainly Tom was restating the mission goals and identifying strategies, Liz contributed to this collaborative effort by asking questions and giving her opinion.

They walk around after reading the mission statement. Liz: "I thought we know our next mission." (She is contesting about where they are going) *Tom: "Well we have one of the way points.* (Problem state identified) *And those are the three things (presented on the right side of screen) that we need.* (Problem state identified) *So we need to get the power coupling* (Mission goal identified)*, up in the upper right corner there, so we have to find the power coupling, which I would imagine is the first thing in the way point, which is that green dot* (Problem state identified)*. Then we have to go find the med vendor and we* *get to go buy a shield.* (Mission goals identified) *" Liz: "OK." Tom: "So I think we need to go out around the same way that we went with the skags.* (Problem state and possible action identified) *Maybe? But it looks like it (waypoint) is almost due south east.* (Problem state identified) *(he goes up to claptrap) and he is not helpful." Liz: "Are we like too far?" Tom: "I don't know."* (Confusion about the problem state) *Text appears on screen Tom reads it out loud. Tom: "To access your map hold select. OK. (He opens his map) So now we have to go outside from where we are then we go into the thing.* (Problem state and possible action identified) *That makes us like, so we turn left once we come out of the gate."* (Problem state identified) *Liz: "OK"*

This conversation took place during one of the early missions. Tom and Liz still did not know how to access the map until the game directed them to do so. We can also see that mainly Tom was identifying all the problem states, possible actions, and end goals of the mission. Liz's questions instigated the conversation. Tom's willingness to elaborately share his understanding of the problem space allowed them to develop a common understanding of the problem.

In addition, before and during most of the missions Tom requested that they should check their inventory/backpack and purchase new equipment before they proceed to take on the challenges of the game. During these extended times (around 4-5 minutes) that they spent on discussing their state, they also talked about their mission goals which allowed them to develop a common understanding of the goals.

Tom: "I will look at my inventory now we have all that stuff. Let's see because some of the stuff that I picked up you probably could more than I can. (He goes into the mission log) So what do we have to do? Dr. Zed, the rewards for the death of nine-toes (he is reading the text) so if we can find TK then we do that. OK." Tom: "OK So we have a cheap *repeater and a plywood sniper." Liz: "I only have one (gun)" Tom: "Yeah because there were bunch of things, but oh you have to be level 4 for that (sniper). So I think I will use the cheap repeater and rusty machine gun, and I have fanged repeater." Liz: "Oh that even have the 100% (reading one of the specs)" Tom: "Oh I see it is fanged because it has a blade on it so for melee damage if I try to punch somebody with that gun it doubles my damage, which is nice to know actually. So what do I have over here? So neither of us level for so. I mean if you want either of these guns you are welcome but probably your two equipped guns are better than these (guns in his backpack)." No response from Liz. Tom looks into other views Tom: "So the weapon proficiencies are starting to look better. Kind of sort of. OK. So remember somewhere in the beginning it said the more use a weapon the better it gets, or better you get with it. I think that's what that proficiencies are as we use one more and more then we get better and better at it. So like you are mostly using your pistol." Liz: "Yeah I always run out of ammo." Tom: "Because you are getting good at that though, so that's a good thing. I don't know like if I start using the repeater thing it might be a third weapon in which case it will change."*

In this example we see Tom taking quite some time to examine his backpack, mission log, and gun specifications. His act of checking out his inventory log prompted Liz to check it too. They discussed about the ability of their guns whether they should exchange guns. They also started to strategize about which gun they should use during the missions.

During the combat scenes they still manage to communicate and come up strategies to defeat the enemy. They paid attention to their environments and talked about their ammo and health figures.

Liz: "I can hear people." (Problem state identified) *They look for the bandits. Liz: "Over here out there."* (Problem state identified) *Tom: "They are shooting at you from the other side of the wall."* (Problem state identified) *Tom: "Careful your shield is almost out."* (Problem state identified) *Tom: "Did you just die?" Liz: "Yea." Tom: "Oh I am sorry." Liz: "Oh no it is alright." Tom: "Oh no he has got a shield."* (Problem state identified) *Liz: "Who?" Tom: "The bandit thug that we are currently trying to kill." Liz: "OK I see now on the screen." Tom: "Fall back your shield is out."* (Possible action and problem state identified) *Tom: "OK I am going to just go and punch him because this is apparently not working for me. Can you cover me?"* (Possible action identified) *She was already next to the bandit and shooting at him. Liz: "Where are you?" Tom: "Oh (he sees her next to the bandit) coming." Tom: "Oh we got a skag with him.* (Problem state identified) *No wonder." Tom: "OK we have to get back into town I think."* (Possible action identified) *Liz: "What is that their shield lighting up or something?" Tom: "Yeah they are very well shielded and I am out of ammo for both weapons."* (Problem state identified) *Liz: "I think there is some by you. I will charge."* (Possible action identified) *Tom: "I think we need to stay and shoot at them,* (Possible action identified) *because I can't go out there and save you.*(Stating the reason behind suggested possible action)*" Liz: "That's fine. I will just shoot them until they die."* (Possible action identified) *Tom: "But let's try and work together.* (Possible action identified) *Like if you can sort of guard the gates, I am going to go buy more ammo."* (Possible action Identified) *Liz: "So shoot at them?" Tom: "So don't shoot at them unless they come inside and I am going to buy more ammo."* (Possible action identified) *Liz: "OK." Tom: "Except I can't buy any ammo from the... so cancel."* (Problem state identified) *Liz: "I guess they are not going to come* *in here."* (Problem state identified) *Tom: "Yeah." Liz: "This would be a good place if we need to get something." Liz: "Is there something on the map that can tell us where any ammo is hidden?"* (Possible action identified) *Tom: "I am going to die, don't worry because if I die at least I will have.. umm how do I re-spawn? I might get ammo.* (Possible action, problem state, association Identified) *(he dies and re-spawns) yeah I get ammo when I die." Tom sees her partner is down. Tom: "Don't move I am coming to." Liz: "OK." Tom: "Don't re-spawn." Liz: "Ops we both died."* (Problem state identified) *Tom: "Yup I have been out of ammo." Liz: "That's funny." Tom: "Except this is not helping with the mission at all. Oh well."*

In this example, we see Tom and Liz struggle to defeat the enemy in a combat scene. Even in this difficult situation, they were still able to identify and verbalize problem states, possible actions, and association between actions and states. They proposed several strategies based on their understanding of the problem space. This conversation snippet showcased their successful communication in developing a common understanding of the problem and suggesting possible solutions. They were eventually able to complete this combat scene and continue their gameplay.

Influence of game elements on collaborative problem solving.

Challenge.

The problems that the team faced were more open ended and less challenging in terms of task complexity. However, the gameplay proved itself to be very challenging for Liz during this game. Earlier in the game, Tom was also observed to have a slight difficulty performing some of the complicated actions that this game required players to do simultaneously such as aiming correctly while moving around, or strategizing while in the middle of a combat. However, he never reported any of the missions of the game as challenging as Liz did (Table 43).

Table 43

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Mission 1	Tom	2	31	18	13	0	0	1	0	0	0	9
	Liz	20	20	4	9	0	1	0	1	0	0	0
Mission 2	Tom	4	16	3	2	0	0	0	0	0	0	2
	Liz	18	9	0	2	0	0	0	0	0	0	0
Mission 3	Tom	1	8	6	7	1	0	1	0	0	0	2
	Liz	7	6	2	5	0	0	0	2	0	0	0
Mission 4	Tom	2	16	11	5	0	1	0	0	2	0	3
	Liz	13	8	1	3	0	1	0	1	0	0	0
Mission 5	Tom	2	25	13	6	1	3	0	0	3	0	1
	Liz	13	21	2	9	0	2	0	1	0	0	0

Liz reported that the challenge level for her was at the highest in the opening level, and the reported levels of challenge reduced eventually as she got more used to playing this kind of a game. The high level of gap between the perceived levels of challenge between the players presented itself consistently throughout this session. One of the sections that both teammates thought was challenging was mission one where they had to deal with small dog like animals moving quickly around them and attacking them for the first time. The least challenging level was the mission two where Liz wandered to a wrong direction and did not help Tom in his fighting with skags or obtaining necessary items for the mission. Since she was not in a combat scene Liz rated this section of the game as relatively less difficult than the other sections. Therefore, it can be assumed that the level of challenge for Liz was mostly related to the difficulty of the combat scene, which increased as the team progressed in the game. However, as they progressed they got more experienced and their attacks were giving a higher damage on the enemy even though the enemies were getting tougher.

The unequal levels of perception of challenge between the teammates influenced their group dynamics and caused a skewed distribution in their functional roles. However, while Tom took the lead and proposed most of the ideas that steered them to a solution, the team still managed to develop a common understanding of the problem due to Tom's efforts in sharing his opinions. Even though most solutions and game strategies were generated by Tom, in most cases he still looked for his partner's approval before taking any actions. This allowed Liz to have an opportunity to input her ideas during the problem solving process and help them to converge on a solution. However, due to her low level of experience with first-person shooting games she was highly challenged during this game and she did not to generate ideas for solution as much as Tom did. Therefore, it can be assumed that the difficult gameplay mechanics of this game caused a skewed distribution in their observed functional roles and slightly inhibited their collaborative problem solving process.

Sensory stimuli elements.

During the first section of the game, the team followed the instructions of a robot called Claptrap and a guardian angel, which appeared on the screen before or after a mission. While most of the feedfront elements were easy to follow and understand for Tom and Liz earlier in the game, they displayed weaker understanding of the feedback elements during the early missions. For example, while they were trying to loot the available resource during the opening level, neither of them realized that they were under attack despite the presence of the obvious feedback sensory stimuli elements such as sound of the bandit shooting at them, red banners appearing on screen pointing that they are taking damage, or the screams of their characters as they are getting shot and injured. Another conversation also shows how as a team they tried to make meaning out of some of the sensory elements that this game was throwing at them:

> *Liz: "What is that little indicator on the bottom? Oh just.." Tom: "No I think that's where we each are. I don't know actually." Liz: "I think it is just south west." Tom: "Yeah, you mean what that orange triangle is?" Liz: "No right there right at the bottom. I don't know if it means that there is an attacker?" Tom: "So of it.. I don't know. I don't have that orange thing." Liz: "Because I am still crouching."*

After this first level, the team learned to pay more attention to the feedback elements and incorporated both the feedback and feedfront elements during their collaborative problem solving process. Their attention was grabbed by both auditory and visual sensory stimuli elements such as bandit’s loud talking or flashing indicator lights on screen. The teammates also shared their understanding of the sensory stimuli elements with each other verbally. For example, anytime a text direction appeared on one their half of the screen they read it out loud, or when one of them realized how to utilize a sensory stimuli element such as noise or text that tracks their mission goals he or she pointed this out to the other player.

Sensory stimuli elements helped this team in several different ways. One of the ways the team incorporated sensory stimuli elements was through using them to find their direction in the vast open ended game environment. They carefully observed the flashing diamond, the waypoint, to identify where they need to go to complete the missions. This sensory stimuli element promoted conversations between the players almost always. During these conversations waypoints allowed teammates to propose which direction they should be going. However, Tom’s assumed leader position caused him to propose most of the ideas in terms of which direction the team should go. Even though in most missions they were able to incorporate the waypoint successfully through conversing about it, in one occasion his misunderstanding of the sensory element and lack of conversation caused them to incorporate a wrong solution. In the last mission, when Tom looked at the map he thought another diamond shape (not green colored or flashing) was the waypoint, and misdirected the team towards the false waypoint. Even though Liz saw the green flashy waypoint and somewhat knew where they needed to go (because she was going towards the right direction until Tom ask her to come back around), she did not disagree or say anything that will at least indicate that they might be heading the wrong way.

> *Liz: "Do we go back this way?" Tom: "Well looking at the map. (He opens the map) we can go back out of town the way we used to and then we have to turn right. Umm so it looks like all of the bandits are in that cave system, so I would probably come out and go, I wish there was a cursor we can use, umm in next to the sort of steering wheel location thing and come in that way, because it looks like there is more walls and things that we can hide behind." Liz: "OK.' Tom: "So that would be my suggestion. What do you... Do you think that is a decent plane or?" Liz: "Yeah no." Tom: "I mean the other thing is we can try to sneak into the back, then we run the risk of running all eight of them show up." Liz: "Yeah."*

The team also used the sensory stimuli elements to check on their progress during the missions. Tom was the main person who kept a track of their progress through observing the mission track text that was on his half of the screen. Even though he was the only one paying attention to this sensory element, he sometimes verbally expressed his understanding of the mission goal using this sensory stimuli element.

> *Tom: "So we got two of the eight killed." (He refers to the text on the right of the screen "Bandits Killed: 2/8" with an empty check box next to it)*

Tom: "So we survived somehow and we killed enough bandits that we are ready to turn in the quest." (The text on the screen is "Bandits Killed: 8/8" with a check mark next to it and another text under it reading "TURN IN!")

Liz: "I thought we know our next mission." Tom: "Well we have one of the way points. And those are the three things (presented on the right side of screen) that we need. So we need to get the power coupling, up in the upper right corner there, so we have to find the power coupling, which I would imagine is the first thing in the way point, which is that green dot. Then we have to go find the med vendor and we get to go buy a shield." Liz: "OK."

Besides from allowing team members to communicate more effectively about the mission goals, sensory stimuli elements also helped them realize and talk about their current state of the problem task as well as the possible actions. For example a skag or an enemy noise immediately alerted them, or a green button indicated that they could find guns or ammo.

Tom: "See how it is like blinking green sort of. I bet that's the. So we found the power coupling. But now somebody is shooting at us. (He sees the skags) Oh it is a skag. (He is down) Oh crap."

Tom: "Oh we got money. Where did you go?" Liz: "I am right behind you." Tom: "Ok. I just want to make sure that (He hears a skag noise) and you got a skag still on you? No?" Liz: "Yup there is one right there."

They see boxes that have green lights on them. Tom: "Oh there might be stuff."

Overall observations from this session indicated that while the feedfront sensory stimuli elements such as waypoints, or mission logs promoted conversations and allowed the team to develop strategies together before they take on a mission hence enhancing the collaborative process, the feedback sensory stimuli elements were only used at the individual level problem solving. However, the individual level of understanding of the problem was still shared between the teammates, which then enabled the occurrence of a common understanding of the problem and successful convergence on a solution.

Clarity of goals and rules.

Overall, both Tom and Liz reported that the game goals and rules were clearly presented (Table 44). However it was observed that Tom had a better understanding of the game rules than Liz did. The opening section was rated lowest in terms of how clear it was by both of the team members. During this section, they struggled with gameplay while they were trying to understand the game rules and how to use some of the game objects. As they progressed in the game, their confusion with the game rules started to disappear.

Table 44

Reported Clarity of Goals and Rules

	Clarity of the Goals and Rules	
	Tom	Liz
Mission 1	17	17
Mission 2	19	18
Mission 3	23	28
Mission 4	24	23
Mission 5	26	22

System rules were easily understood by Tom and explained to Liz when she needed. This game did not have as much procedural rules since it provided more of an open-ended environment for the players instead of problems that require them to identify and apply step-by-step actions. The main and repeating procedural rule was the fact that they needed to complete the tasks given to them before they can return any mission to collect the rewards. For example, how they killed, how many enemies they killed, or how they got to the location of the mission were not important to the mission as much as that the mission needed to be completed by completing specific tasks such as fix a med vendor machine, meet a game character, or kill a group of enemies. During understanding the operational rules Liz requested a lot of help from Tom who seemed to be clearer about them. Liz seemed to be confused about how to recognize her partner and distinguish him from all the enemies during combat scenes (Liz: *"How do I even know which one is the bad one?*"), or how to use game objects such as shields, guns, ammo (Liz: *"How do I use it?"* Tom: *"The shield?"* Liz: "Yeah." Tom: *"It is already equipped. See. Look at your health you see how you have that shield there."* Liz: *"Oh OK is there a way we use it?"* Tom: *"When we get hit the shield will drain before our health will drain.")*

The mission goals were always clearly stated on the mission acceptance screen and in their mission log. Alongside of that, a short text indicating the tasks related to a mission and showing their progress was also presented on their screen all the time during a mission. This clear presentation helped Tom to understand the mission goals easily. However, Liz mostly relied on Tom to accept the missions and explain it to her what needs to be accomplished.

> *Tom: "Wow. This I think is a quest. It looks like. Yeah. So we have to open the building and talk to Dr. Zed to get this quest. Yeah let's accept it." … Tom: "He is a pleasant looking fellow. And there he is." Liz: "Do we kill him?" Tom: "No I don't... The mission was to go talk to him."*
>
> *Tom: "Ok to the map (chuckles)" He opens the map and locates the flashing diamond. Tom: "So that's where the bandits are." Liz: "Where?" Tom: "You see in the lower left of the map, where that diamond is blinking?" Liz: "Yeah." Tom: "So we have to go there and kill 9 bandits, or 8 bandits (correcting himself)." Liz: "OK"*

Overall the clear presentation of mission goals along with Tom's approach to explain the goals to his partner helped the team in developing their own common understanding of the goals. However, most of the game rules confused Liz throughout the game and required her to rely on Tom to understand the game rules, which in return promoted more conversation between the teammates. Having a better understanding of the mission goals and game rules allowed Tom to take the leader position and provide more ideas for the solution. Collaborative problem solving during this session was only possible because Tom was able successfully to communicate with his partner about his understanding of the problem task since they were all clearly presented.

Within Case 7 – Group 4 (Mike and Dan) Playing Borderlands

In this session Mike and Dan played the first eight missions of *Borderlands*. In their first and only session together, both team mates engaged in very little conversation during this action pact first person shooting game that has elements of RPGs. While Dan chose the Roland (Soldier) character, Mike preferred to play the game as Mordecai (Hunter). Both team mates were experienced game players and they were observed to be confident through all the combat scenes of this game. Throughout the game, the team mostly followed the missions given to them, even though the game environment was open enough for them to wander around anywhere.

Collaborative problem solving.

As the tutorial session of this game was well integrated in the game's plot, the team mates started to learn how to play the game from the early missions. Each mission gradually introduced them to new game objects such as how to find/deploy new guns, grenades, and body shields as well as increasingly tougher enemies. As the players advanced in the game, they also gained the ability to level up and use more powerful guns. The players accessed the new guns, ammo, and money to buy these guns through completing missions, looting after combat scenes, and from vending machines. Both game characters had unique skills and their unique skills gave more power to the equipment they were using. Also the resources available to them were limited. Therefore, the allocation of recourses during this game was an important part of the collaboration. While at the early missions the team mates did not pay too much attention to what they were collecting and they did not check with their partners if they needed anything before they took it, later in the game they shared the resources more meaningfully. They learnt how to pay attention to their partner's situation and share the available ammo and health kits. Their conversation changed from *Mike: "Oh I am like near dead." Dan: "Oh I just took health I am sorry."* to *Dan: "Get some more health here."* Also, they began to share their guns:

> *Dan: "Do you want this repeater (gun) here? How do I give you stuff?" He drops the repeater gun for his partner. Dan: "That should be an upgrade right there if you can pick up this gun. It's a better pistol." Mike picks up the gun.*

This team had the least amount of conversation and collaboration among all the other teams, as can be observed from the frequency table of their functional roles presented in Table 45. Majority of their actions in the game world was execution of a move without consulting a partner (84%). Collaborative discourse (16%) was observed rarely and was mostly about finding directions in the massive game world. In general both team mates were equally nonresponsive to the idea of planning a strategy or working collaboratively to complete the missions, but at certain occasions Dan seemed to have more desire to collaborate. During the rare moments of collaboration, Dan was observed to propose more ideas (65%) and tried to engage Mike in conversations, in which some cases was responded with silence from his partner.

Table 45

Frequency of Functional Roles Assumed During Borderlands

		Mission 1		Mission 2		Mission 3		Mission 4		Mission 5		Mission 6		Mission 7		Mission 8		Mike Total	Dan Total	Total
		Mike	Dan	Mike	Dan	Mike	Dan	Mike	Dan	Mike	Dan	Mike	Dan	Mike	Dan	Mike	Dan			
Execution	N	14	15	15	16	13	13	6	6	10	6	15	12	10	14	71	74	154	156	310
	%	48.28	51.72	48.39	51.61	50	50	50	50	62.5	37.5	55.56	44.44	41.67	58.33	48.97	51.03	49.68	50.32	84.01
Proposal	N	1	2	2	1	2	3	0	1	0	1	0	0	0	2	2	3	7	13	20
	%	33.33	66.67	66.67	33.33	40	60	0	100	0	100	0	0	0	100	40	60	35	65	5.42
Implemen-tation	N	2	1	3	3	3	3	1	1	1	1	0	0	2	2	4	4	16	15	31
	%	66.67	33.33	50	50	50	50	50	50	50	50	0	0	50	50	50	50	51.61	48.39	8.4
Modifica-tion	N	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	%	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0.27
Contesta-tion	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rejection	N	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	%	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	100	0	0.27
Acceptance	N	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	4	2	6
	%	0	0	50	50	50	50	100	0	100	0	0	0	0	0	0	0	66.67	33.33	1.63
Reasoning	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Testing	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Explanation	N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	N	17	18	22	21	20	20	8	8	12	8	15	12	12	18	77	81	106	105	369
	%	48.57	51.43	51.16	48.84	50	50	50	50	60	40	55.56	44.44	40	60	48.73	51.27	50.24	49.76	100

As lack of collaborative functional roles might suggest, there was very little collaborative problem solving during this session. As both experienced players, the team mates did not need to problem solve or discuss strategies since they were used to just jumping into the combat scene to kill or be killed and spawn back to fight again. They only talked about what direction that they should be going, and once the direction was figured out the rest was about taking action and killing enemies.

Dan: "Let's see where is the way we are going? It's back beyond the gate." Mike: "Umm I can't believe that. Let's just head to skag gulley."

Mike locates the flashing diamond. Mike: "OK" Dan: "So keep on going south?" Mike: "Looks like it."

Dan: "OK where are we supposed to go?" Mike: "Umm stolen food or something."

Dan: "We are going back this way? (He looks at the map) I guess so."

Mike: "Umm where are we going?" Dan: "Where to?" Mike: "Umm going down?"

Dan: "Yeah we got to go. We got to go straight through I guess. That is the way you are going. That's the right way."

The team rarely attempted to discuss the mission goals or identify problem states and possible actions. However, they were still successful at completing the given missions without much observed collaborative action. Since both team mates stayed together throughout the missions and followed each other without much conversation, it can still be assumed that through sharing the same environment and being exposed to the same problem tasks they somehow have the same understanding of the problem. However, their lack of conversation and interaction with each other made this really difficult to observe. Unfortunately, the open-ended nature of this game failed to engage the experienced players to effectively collaborative during their problem solving activity. Even a further claim can be made that the players in this team did not have to problem solve during this game as the nature of the game was quite familiar to them and they performed actions without much thought.

Influence of game elements on collaborative problem solving.

Challenge.

During this gameplay it was not clear whether the perceived level of challenge had any influence on the distribution or the frequency of functional roles. In general Dan rated the missions less challenging than Mike (Table 46), and Mike indicated that he got slightly bored during these missions. As mentioned before they mainly executed actions without much discourse, and occasional proposal of ideas were mostly implemented without discussion; hence the lack of variety in their functional roles observed during this session.

The most challenging mission was the last one based on my observations of their gameplay as well as their scorings of the missions. During this mission the team got diverted from the actual projected path and started getting into combat scenes with enemies that were too high ranked. This unique event still did not promote a collaborative action taking or strategizing for this team. They both jumped into the combat scene without much thinking or talking about it and kept dying and re-spawning. They continued to take this individualistic approach until all the enemies were killed. This event showcased that increased challenge due to the harder gameplay (not due to a more complex problem) did actually inhibit them from having more conversation and made them focus more on the action scenes. Unfortunately the complexity of the problems they faced during this game did not change as much. Therefore, how the challenge due to the complexity of the problem influenced construction of the joint problem space was not clear during this game.

Table 46

Frequency of Functional Roles and Reported Challenge Levels

			Functional Roles									
		Challenge	Execution	Proposal	Implementation	Modification	Contestation	Rejection	Acceptance	Reasoning	Testing	Explanation
Mission 1	Mike	7	14	1	2	0	0	0	0	0	0	0
	Dan	4	15	2	1	0	0	0	0	0	0	0
Mission 2	Mike	2	15	2	3	1	0	0	1	0	0	0
	Dan	3	16	1	3	0	0	0	1	0	0	0
Mission 3	Mike	4	13	2	3	0	0	1	1	0	0	0
	Dan	3	13	3	3	0	0	0	1	0	0	0
Mission 4	Mike	9	6	0	1	0	0	0	1	0	0	0
	Dan	5	6	1	1	0	0	0	0	0	0	0
Mission 5	Mike	9	10	0	1	0	0	0	1	0	0	0
	Dan	3	6	1	1	0	0	0	0	0	0	0
Mission 6	Mike	10	15	0	0	0	0	0	0	0	0	0
	Dan	2	12	0	0	0	0	0	0	0	0	0
Mission 7	Mike	8	10	0	2	0	0	0	0	0	0	0
	Dan	5	14	2	2	0	0	0	0	0	0	0
Mission 8	Mike	13	71	2	4	0	0	0	0	0	0	0
	Dan	8	74	3	4	0	0	0	0	0	0	0

Sensory stimuli elements.

At the earlier stages of this game, the team was more responsive to the sensory elements that they encountered. Even if it was a one sentence blurb, a team member said something about it when a new kind of sensory stimuli was introduced to the environment. For example, when the team first time saw a glowing line on top of looting items, they had a small conversation about it:

Mike: "Is that the stuff glowing on the ground?" Dan: "This is cash."

They helped each other understand how the game world worked with the help of the sensory stimuli elements such as text boxes appearing on the left side of the screen, or glowing lights on the object of interest, or simply with verbal instructions given by a Claptrap or a Guardian Angel. For example when Mike missed to observe a piece of instruction, Dan occasionally made an effort to utter what he observed out loud to his partner.

Dan: "I guess R3 is the melee attack."

Mike: "Is that everyone?" Dan: "Yeah I think so. It said that. It says the mission turn in."

Dan: "Three out of four?" Mike: "Yeap."

Majority of their conversations revolved around trying to find directions in the game world, and they took advantage of sensory stimuli elements extensively for doing so. The game used a flashing green diamond at the bottom of the screen and as well as in the map view to direct players to the mission location. Both Mike and Dan was paying attention to the green diamond flashing on their screens, but they also utilized the map views and the diamond in that map view to figure out the direction they need to go.

Mike: "OK. Follow the green diamond thing." Dan: "Yeah I guess so."

Dan: "We going back this way? (He looks at the map) I guess so."

Dan gets to a cave. Mike: "It’s the beginning." Dan: "Is it? Yeah." Dan looks at the map and finds the green diamond on the map. Dan: "Yeah we got to go. We got to go straight through I guess. (Meanwhile Mike moves towards the right direction) That is the way you are going. That's the right way."

Considering their very limited attempt to converse, sensory stimuli elements helped them take a language that is more collaborative in nature such as proposing an idea, in this case mostly proposing a direction to go. Sensory elements also helped them individually in locating resources, identifying enemies, and finding interact-able game objects. However, overall it was observed that the sensory stimuli elements of this game did not promote or trigger much collaborative functional roles.

As for constructing a shared understanding of the problem, the team occasionally talked about the problem states and the possible actions. The mission goals were also hardly discussed. It was observed that in general the team chose to ignore most of the sensory stimuli elements such as text explaining the missions or their gun specs, even if it was just for their own individual problem solving activity. However, there were a limited number of observed occasions related to constructing a shared understanding of the problem, where some of the sensory stimuli elements seemed to play a role. Here are the instances where they seemed to utilize the sensory stimuli elements during their feeble joint problem solving activity:

> *After they get out of the door, Dan says "Which way do you want to go?" Mike looks around and says: "Um, I don't know let's go this way." They start moving towards the way Mike point at, but then Mike realizes: "Let's follow the... I mean the diamond goes back." So they turn around. Dan: "Let's see the diamond on the map. How do I get to the map? (he figures it out) yeah right it is that way."*
>
> *After a combat scene, Mike: "Is that everyone?" Dan: "Yeah I think so. It said that. It says the mission turn in (on the side of the screen the "Mission: Turn In" text appeared)."*
>
> *Mike locates the flashing diamond. Mike: "OK" Dan: "So keep on going south?" Mike: "Looks like it."*
>
> *Dan: "OK where are we supposed to go?" Mike: "Umm stolen food or something." (Mike is somewhat restating the mission goal based on the text explaining the mission.)*

Clarity of goals and rules.

Both team mates reported that the goals and the rules of this game were clearly presented to them in general (Table 47). In addition, review of their gameplay also reflected that the team did not have difficulty understanding the goals or the rules of the game.

Table 47

Reported Clarity of the Goals and Rules

	Clarity of the Goals and Rules	
	Mike	Dan
Mission 1	27	19
Mission 2	26	18
Mission 3	16	21
Mission 4	26	17
Mission 5	24	19
Mission 6	25	19
Mission 7	23	20
Mission 8	20	24

In this case, clearly presented goals through long text explaining the mission and short text in checklist format appearing on the screen allowed both players to apprehend the goal of the missions easily. However, this did not help derive collaboration between the experienced players of this team. Throughout the gameplay the team ignored long text boxes explaining the mission, and sometimes paid attention to game characters speaking to them or short checklist that appeared on the screen after a mission was accepted.

During this session the team only talked about operational rules at the beginning of the game when they were still trying to figure out how the game environment worked. During these brief conversations the team mates shared their understanding of the rules with each other, which can be assumed as part of building a shared understanding of the problem. However, no conversation about the procedural rules which is more deeply associated with building a shared understanding of the problem was observed during this session.

Within Game - Across Group: Borderlands and Collaborative Problem Solving

This unique first person shooter role playing game provided the most challenging game play for the participants of this research study. Played by two groups that differed significantly in terms of their gameplay experience levels, this game provided a great insight to how open ended problem solving environments should be designed to foster collaborative problem solving. Two groups played this game for only one session each. The list of completed missions for each group is presented in Table 48. Group one, Tom and Liz, played *Borderlands* during their fourth session together. Group four, Mike and Dan, however played this game during their first and only session together.

Table 48

Completed Missions for Each Group

Groups	Completed Missions	Number of Sessions
Group 1	The Doctor is In Skags at the Gate Fixer Upper Blinding Nice-Toes Nine-Toes: Meet T.K. Baha	1 (Fourth Session)
Group 4	The Doctor is In Skags at the Gate Fixer Upper Blinding Nice-Toes Nine-Toes: Meet T.K. Baha Nine-Toes: T.K.’s Food Got Granades? Nine-Toes: Take Him Down	1 (First Session)

Group one was very inexperienced with first person shooter genre and was observed to struggle with the gameplay mechanics at first. However, while their struggle with the gameplay slightly decreased their level of collaboration, in general they still managed to develop their joint problem space successfully. As usual Tom took the leader role and communicated with his partner well through this session. The difficulty of this game forced them to come up with strategies and work together. Whereas, group four consisted of two of the most experienced players that participated in this study and had no trouble playing this game. This group demonstrated very little collaboration and frequent individualistic problem solving. Collaborative problem solving was observed in rare occasions. Unfortunately the attributes of this game failed to promote collaboration between the highly experienced players of group four.

Challenge.

The sections played during this study did not offer various levels of task complexity, however overall the gameplay was challenging for group one due to their inexperience with first person shooter games. Furthermore, the gap between the perceived levels of challenge between teammates of group one resulted with an unbalanced distribution of functional roles skewed towards Tom. Even though he shared his ideas and seek input from his teammate Liz, the highly challenging combat gameplay of *Borderlands* inhibited their collaborative problem solving at times. On the other hand Mike and Dan did not feel challenged as much as group one, but also did not showcase a healthy collaborative process either. Even the most challenging level due to difficult gameplay for this group did not promote any collaboration, and lead them towards being more individualistic in their approaches to solve the problems.

Sensory stimuli elements.

As usual while group one took full advantage of sensory stimuli elements during construction of their shared understanding of the problem, group four's utilization of sensory stimuli elements was minimal. More specifically, Tom and Liz incorporated feedfront elements to communicate more efficiently and identify problem states. Feedback sensory stimuli elements were mainly used in individual problem solving processes that were later shared with the partner. For Mike and Dan, the feedfront sensory stimuli elements helped them take on a language that showcased some collaboration, but overall this team conversed very little and solved problems very individualistically. On the light of these findings it can be concluded that the collaborative problem solving process during *Borderlands* was enhanced mainly by the feedfront sensory stimuli elements for the inexperienced group but not for the experienced group, and the feedback sensory stimuli elements did not play any role for either group in relation to collaborative problem solving.

A list of sensory stimuli elements and their level of utilization during collaborative problem solving process for each group is provided in Table 49.

Table 49

Sensory Stimuli Elements and Their Level of Utilization during Borderlands

Sensory Stimuli Elements	Level of Utilization Based on Discourse	
	Group 1	Group 4
HUD - health, experience, ammo	Low	None
Text explaining gameplay	High	Low
Supporting Game characters such as claptrap, guardian angel, bandits	High	None
Music - changing tone during battle both teams	None	None
Playing game characters - screaming while hurt or talking	None	None
Red banners appearing when shot	None	None
Waypoint - shining diamond	High	High
Progress related text	High	Medium
Mission logs/acceptance text	Low	Low
Color and shape - like green shiny stash on ground, money ammo colored yellow on ground, etc.	High	Low

Clarity of goals and rules.

This game clearly presented its mission goals in a written format along with verbally and visually reinforcing it. Both groups indicated that the goals and rules of the game were easy to understand. However, only Tom was observed to reinstate the goals in his own words allowing the group one to develop a shared understanding of them. Also the system rules of this game were discussed by Tom and Liz to help her understand the gameplay. Mike and Dan did not communicate about the mission goals other than one small instance where Dan was not sure and asked Mike about the goal of the mission, in which a two word response was given by Mike to explain. Overall the clarity of the goals allowed both experienced team mates to have their own understanding easily, but did not promote any conversation to share their understandings with each other. On the contrary, in group one, when one team mate had a clear understanding and the other teammate did not, a conversation about game goals and rules became necessary for successful mission completion.

Chapter 6 Summary

This chapter provided the results of within case analysis for two first level cases: Within Case 6 – Group 1, and Within Case 7 – Group 4. Each section presented detailed information about the player interactions and discourse that took place during the gameplay sessions. The influence of game design attributes were discussed at the individual group and session levels. At the end of the chapter, results across all two groups were collapsed and presented in the within game across group section to identify the similarities and differences in the associations between game design attributes and collaborative problem solving across groups with different players and dynamics.

Chapter 7 - Discussion

The main goal of this research study is to explore the ways that the design of digital games can influence the collaborative problem solving processes of players. For that reason, three key game design attributes – challenge, sensory stimuli elements, and goals and rules – were studied in terms of their association with collaboration and joint problem solving activity of two person teams. In this chapter, findings of this study are first discussed across three games to highlight design similarities and differences. Next, findings regarding the three research questions are discussed. Wider implications of these findings are discussed in the final chapter.

Across Case: Differences and Communalities in the Influence of Game Design Elements

This study examined three popular collaborative video games with varying problem structuredness and complexity from three different genres. This purpose of this study was to understand the potential relationships between the game attributes and collaborative problem solving processes of the players. In order to achieve this, players' interactions, discourse, and gameplay was studied to identify the degree and the depth of their participation as well as to identify how they constructed their joint problem space. Through examination of the frequencies and distribution of the players' assumed functional roles, the researcher analyzed the teams' collaborative nature. The construction of joint problem space was studied through examining whether the teammates constructed a shared understanding of the problem and identified problem states, possible actions, and associations. Each of these constructs then was inspected in terms of their link with specific game attributes.

In this section, I will discuss the similarities and differences of three games in supporting or hindering collaborative problem solving process. It is important to note that each game provided the players with a different environment filled with problem tasks that varied in structure and complexity. While playing *Portal 2* players strictly encountered well-defined problems that varied in complexity. In *Indiana Jones 2: The Adventure Continues*, players faced problem tasks that differed both in structure and complexity. Conversely, *Borderlands* mostly provided players with open-ended problem tasks that did not differ in terms of complexity. Keeping these differences in mind, comparison of findings across games revealed several important topics.

Compared to other two games, Portal 2 game environment was more supportive of collaborative meaning making regardless of experience levels of teammates. One aspect that influenced the group dynamics was personal differences in problem solving and social interactions. For example, while both group one and group three had an inexperienced and a more experienced player in their team, in general, group one was better at reaching to a shared understanding of the problem because of Tom's style of problem solving and openness to share his thoughts. Conversely, Mike seemed more reserved and not willing to communicate his understanding of the problems with his partner. Therefore, group three needed a bit more structure and an external support when it came to collaboratively solving the problems. In this context, *Portal 2* game environment promoted collaboration between partners. Considering it only provided well-structured problems in a puzzle format, the game had great control over what the teams had to do to solve problems. Because of its structured nature, this game exposed the players to different pieces of the puzzle which forced them to communicate their understanding of the problem states, and possible actions to be able to identify a converged solution. One way that this game was able to force players to communicate their understandings of their surroundings was to constrain them to different locations. Sometimes this game required one player to be in a different room behind a closed door where only he/she can see what is inside that room while the other player has to rely on his/her description of the possible actions that they can take in that room. The game environment of *Indiana Jones 2* changed from structured to more open-ended as the players switched from story levels to hub levels. During story levels players were forced to share the same environment and which allowed them to be exposed to the same sections of the problem, while hub levels did not constrain the players to be in the same environment neither did it give them structured problems to tackle. Sometimes, the puzzle problems in story levels required specific skills that were assigned to only one of the game characters. This forced both teammates to perform actions to solve parts of the problem. Being forced to solve the parts of the problem still did not promote conversation as much as the puzzle structure of the *Portal 2*. Borderlands puts the players in a big open ended world where no restriction was made to keep or separate the players. The nature of ill-defined problem tasks in *Borderlands* also did not require them to work together. Therefore, the structure of the game environment did not support collaborative meaning making for experienced players. To sum it up, the different environment and problem structures of the games promoted different levels of collaborative problem solving. While the *Portal 2* game environment always forced teams to work together to solve the problems, *Indiana Jones 2* sometimes required teams to work together, and *Borderlands* never required the teams to work together.

Complex tasks fostered collaborative problem solving. While both *Portal 2* and *Indiana Jones 2* provided changing levels of problem complexity, *Borderlands* only provided varying level of challenges based on changing the difficulty of the gameplay. Unfortunately, increasing the gameplay difficulty did not foster collaborative problem solving during any of the games examined. When exposed to difficult gameplay, the inexperienced players of this research were observed to be more confused and not coordinated enough to follow the difficult game mechanics, and the experienced players were observed to be focused on overcoming the challenge themselves rather than taking a collaborative approach. However, when the teams were facing a complex problem task in most cases they ended up solving the problems together, as it was highly challenging for one person to solve the problem alone. In addition it was also observed that the sensory stimuli elements were incorporated more by even the most the experienced teams when they faced a complex problem task.

Feedfront Sensory Stimuli Elements were more essential compared to feedback sensory stimuli elements for both individual problem solving and/or collaborative problem solving for all three games. All three games used in this research incorporated sensory stimuli elements as feedfront and feedback mechanism in their designs. Even though the function, presentation and amount of these sensory stimuli elements varied across games, it was observed that in general feedfront sensory stimuli elements were more frequently used by the participants during their collaborative problem solving. For an instance, in *Portal 2*, the teammates commonly utilized symbols and pictures presented on floors, buttons or screens that explained the function of an object, indicator lights that told them which objects are related such as buttons and doors, and most importantly distinct color and shape of game objects that indicated them the possible use of that object. All these feedfront sensory stimuli elements triggered conversation between the teammates starting a discussing about the problem that they will be facing which then as a result helped them identify the problem states, possible actions, and associations. In some cases, where collaboration was not favored, these feedfront sensory stimuli elements still helped the players during their individual problem solving processes which sometimes were shared with the partners afterwards. Similarly, during *Indiana Jones 2*, feedfront sensory stimuli elements such as flashing arrows, flashing text, moving Lego pieces or distinct color and shape of objects played an important role in teams' collaborative problem solving processes. *Borderlands* was not supportive of collaboration as much as the other games and even the sensory stimuli elements were not as helpful. This being said, when the groups played this game they utilized mostly feedfront sensory stimuli elements during their scarce collaborative problem solving processes. Feedback sensory stimuli elements were sometimes observed to help the players during their collaborative problem solving process as well. They supported the teams' process through helping them verifying or denying their proposed solutions or informing the team of problem states and possible actions. Examples of these can be found in *Portal 2* as ticking noises that informs the team regarding their limited time to go through a door, or in *Borderlands* as the display of progress related checkboxes that informs players about their state of the problem task or required actions to complete the task. However, in general feedfront sensory stimuli elements generated more conversations between teammates that was collaborative in nature then feedback sensory stimuli elements across all three games. As a final note, it is important to recognize that when the differences in the presentation, function, and amount of sensory stimuli elements were considered, the level of support for collaborative problem solving in each game was observed to vary. More discussion on this issue is provided in the final section.

Unclear presentation of goals promoted more conversation between the teammates and helped players generate a common understanding of the game goals. The three games utilized in this study varied considerably in their ways to present the game goals to the players. *Portal 2* incorporated obvious repeating goals (i.e. exit the chamber) for each level. *Indiana Jones 2* vaguely presented overarching goals through cut scenes for each story level, but the specific sections goals differed and were not presented. *Borderlands*, on the other hand, clearly presented the mission goals in text format. While most groups generally did not converse about the game goals, group one was an exception. Tom and Liz talked about the goals of each section that they were playing most of times during this research. During *Portal 2* they had smaller conversations about locating the exit doors in most levels, which was an evidence of a common understanding of the game goal. However, during *Indiana Jones 2* they had the most extensive conversation about the game goals since it was not clearly presented for them. Tom was more aware of what the game goals were and the gap in Liz's understanding of the goals triggered conversations between the teammates and helped them reach to a shared understanding. During *Borderlands* conversation about mission goals were rarely observed.

Review of the Key Findings

The researcher posed three major sets of questions during this dissertation research. Each set contained substantive questions about the influence of game design attributes on collaborative problem solving processes. The following discussion of the results is framed within these research questions.

In Response to Research Question 1 – Understanding the Influence of Perceived Level of Challenge on Collaborative Problem Solving.

Research suggests that the effective games should provide an optimal level of challenge for the players (Malone, 1981; Garris et al, 2002). To obtain the optimal levels the games should have progressively increasing difficulty levels (Garris et al., 2002), uncertain outcomes (Malone, 1981) or continuously adjusting levels of challenge (Rani, Sarkar, & Liu, 2005). However trying to understand how to obtain optimal level of challenge without understanding the reason the challenge exists in the first place might be an incomplete approach. This study examined the influence of challenge on the collaborative problem solving process of the teams, in doing so it also examined the reasons for the challenge to exist. Two main challenge types were commonly encountered throughout the gameplay sessions: Challenge due to the difficult gameplay mechanics such as difficult to maneuver moves that requires an extensive hand-eye coordination and quick action/reaction and challenge due to a complex problem task faced in the game.

In reviewing the perceived level of challenge, the researcher identified that the balance in collaboration was disturbed if there was a high gap between the reported challenge levels of the team mates. This case was especially intensified if the challenge was due to the lack of players' gameplay skills. In two of the teams, unbalanced game dynamics were observed at certain parts of the game due to the lack of gameplay skills of one of the players. When this situation arose the experienced player mostly took charge and led the team towards a successful solution. Although sometimes the collaboration was unbalanced, some teams still managed to create a joint problem space. However in these cases, creating a joint problem space mostly depended on the experienced player's ability to communicate his/her understanding of the problem.

Literature generally suggest that while too much challenge might discourage players, too less challenge might bore them (Rani, Sarkar, & Liu, 2005; Wilson et al. 2010). However, in the case of co-op games the high levels of challenge which might have been frustrating for one person allowed both teammates to be more actively involved in the problem solving activity. Especially if the challenge was due to a complex task that the team was facing, collaboration levels of the team mates were observed to be more balanced. This gave a chance to both teammates to contribute to collaborative problem solving process and nullified the effects of gameplay skill discrepancy between the players. Unlike collaboration levels, construction of the joint problem space was somewhat disturbed by very high challenge levels. The teams lacked at foreseeing a complete solution without taking any actions and experimented with actions without knowing the consequences when they encountered a highly challenging problem. Breaking up the problem into smaller tasks helped some of the teams during developing a shared problem space and converging on a solution. Another important finding of this study was that the experienced players started to pay more attention to the sensory stimuli elements when they faced a complex task.

In response to research question 2 – understanding the influence of sensory stimuli elements on the collaborative problem solving.

One of the main themes that emerged from this study is that the sensory stimuli elements in games should be examined through three dimensions: their function in the game, the way how they are presented to the players, and their amount in the game. In the following sections, the influence of these three dimensions of sensory stimuli elements on collaborative problem solving is discussed in detail. First, two main functions, feedfront and feedback, of sensory stimuli elements discussed. Next, the presentation of sensory stimuli elements are discussed in regards to how subtle or obvious they are. Last, the discussions on how the amount of sensory stimuli influenced the collaborative problem solving process are provided.

The Function of Sensory Stimuli Elements.

Providing sensory stimuli elements in games may have various purposes such as directing the players towards a goal, informing the players of possible actions, or confirming/invalidating an action taken in the game. However, eventually all sensory stimuli elements in games can be classified under two categories: feedfront and feedback elements.

The use of sensory stimuli as feedback elements is a fairly common approach discussed in games literature. Besides from keeping the players engaged and grabbing their attentions, games also utilize sensory stimuli elements to provide restrictive and confirmatory feedback that communicate with the players about the correctness of their actions. Therefore most players rely on these feedback sensory stimuli elements to understand their environment and learn how to successfully navigate through the game world. For example in *Portal 2* the research participants learnt that they cannot walk through acid pools as they died and reassembled when they fell into one. These feedback sensory stimuli elements helped players to understand the operational rules at individual levels and sometimes generated conversations as a player in a team was not clear about them. Therefore, some of the conversations triggered by feedback sensory stimuli elements were incorporated in the teams' attempts to understand the game rules which are a part of collaborative problem solving processes. However, during this study it was observed that the utilizations of feedback sensory elements did not generate collaborative problem solving discourse as well as feedfront sensory stimuli elements.

On the other hand the use of sensory stimuli elements as feedfront mechanism is not a commonly discussed phenomenon. This study suggested that one way that the games incorporate feedfront sensory stimuli elements is as scaffolding mechanisms that teaches the players how to play the game and how to collaboratively solve the problems. Like in any effective scaffolding procedure, the scaffolding is gradually introduced and is expected to be gradually removed as the learners get the grasp of the situation. The games that were analyzed in this study exhibit a good example of this concept, but not all the games were able utilize scaffolding through feedfront sensory element to enhance collaborative problem solving. *Portal 2* utilizes verbal feedfront elements through the voice of Glados to provide scaffolding for the players for the first a few testing rooms. These verbal sensory elements disappear as the players advance in the game. This kind of visual sensory stimuli element is progressively removed from the game in the further chapters as the players are expected to know how to utilize the similar game object. *Borderlands* took a similar approach with giving guidance to the players using a supporting game character, a robot called Claptrap, at the beginning of the game but the main purpose of this tutorial was to get players accustomed to the game controls and actions. Scaffolding in this game ended abruptly and did not guide them towards being collaborative problem solvers. Also, the open-ended nature of *Borderlands* made it harder for the game to scaffold towards the solution as the solutions of ill-defined problems are known to be multi-dimensional and not definitive. A similar strategy is utilized in *Indiana Jones 2: The Adventure Continues* game. Many initial encounters with game objects such as moving Lego pieces or sparkling patches on the ground is accompanied with a flashing text on the screen indicating how that game object should be used. While the experienced players did not pay attention to these scaffolding procedures, some of the less experienced players and the teams made full use of these sensory stimuli elements to learn how to play the game quickly. When the teams had mixed level of expertise the need for scaffolding sensory elements were at the least level, as the team mates tried to learn from each other more so than they would follow instructions from the game. At the scaffolding level, it was observed that the sensory stimuli elements were obvious and many in numbers, and the placement of the sensory stimuli elements were just before the necessary action was needed.

Besides from scaffolding, some feedfront sensory stimuli elements were used throughout the game to provide guidance to players. *Portal 2* provided directive and informative suggestions for the payers through presenting wall displays that has possible actions expected in the testing course or through arrows pointing at the objects that needs to be utilized. *Indiana Jones 2* incorporated more obvious sensory stimuli elements such as flashing text on screen that explains the objective of the game section, or color change in crosshair if an object is interact-able. These directive and informative sensory elements were mainly incorporated by the players during their problem solving activity. The inexperienced teams paid more attention to these kinds of sensory stimuli elements and developed a better shared understanding of the problem through conversing about the sensory stimuli element. Through their conversations triggered by these directive and informative sensory stimuli elements, these teams were able to identify possible solutions and come up with a plan before they take any action in the game environment. At this level, the sensory stimuli elements can be more subtle to enhance problem solving activity without presenting a complete solution. For example, while *Portal 2* provided more subtle clues to how to solve the problem, *Indiana Jones 2* gave obvious clues about what needs to be done. In both cases if the team paid attention to the feedfront sensory elements they had a more effective collaborative problem solving process in the game that has a more subtle way of directing the players towards the solution. In this sense *Portal 2* was more successful at getting the players to work together to come up with a solution. *Indiana Jones 2* gave most of the pieces of the solution away through obvious feedfront sensory stimuli elements and promoted the teams to work together on only some parts of the game when the sensory elements were more subtle. Also *Indiana Jones 2* provided many more sensory stimuli elements than *Portal 2* due to its more complicated environment. However, it was also observed that in some cases players got used to solving the problems through getting clues from the feedfront sensory stimuli elements and were not able to converge on a solution without the feedfront element when it was not provided. Both teams who played the *Indiana Jones 2* game ended up solving couple of the puzzles by chance without understanding how they accomplished it.

The main way how the feedfront sensory stimuli elements enhanced team's collaborative problem solving was through awaking their curiosity by catching and directing the players' attention to a specific point, and was through allowing the team members to realize the gaps in their understanding of the problem. The best example of this concept was observed in *Portal 2* when the teams were trying to figure out why there was a moving platform that revealed a group of turret robots when a floor button was stepped on. Even though lowering the platform did not do anything specific towards getting one step closer to the solution, it made all the teams question the utility of it by catching their attention. This resulted with teams focusing on the phenomenon and discussing its potential use. Confused at some times, teams might have incorporated this game action in wrong ways initially, but eventually they all were able to understand its utility and come up with a solution.

There were also occasional sensory stimuli elements that were used with no functionality other than decorative purposes. Even though this kind of sensory stimuli element provides an ambiance for the game environment, it also causes some players and teams to be confused. In the case examples provided in earlier chapters, it can be observed that all the teams were diverted from their path to the solution by some sort of a decorative sensory stimuli element whether it was a camera moving on the wall, or a large shiny red jewel stone presented on a wall.

Presentation of Sensory Stimuli Elements.

The second essential aspect of sensory stimuli elements is how it is presented to the players. Presentation of a sensory stimuli element can vary from being subtle (e.g. color or shape difference) to being obvious (e.g. flashing text or objects on the screen).

While common sense might dictate that games should use a balanced mix of subtle and obvious sensory stimuli elements, this study pointed out that successful presentation of the sensory stimuli elements depends on it is function. If the purpose of the sensory stimuli element is to scaffold it was observed that a combination of obvious and subtle elements was needed. However, if the purpose was to direct the players towards a convergent solution then subtle sensory stimuli elements were more successful at promoting a collaborative approach. The games that started with more obvious and some subtle sensory elements and reduced the number of obvious ones over the time while keeping the number of subtle sensory elements were more successful at keeping the collaborative process vibrant. *Portal 2* was a great example of this successful transition from the obvious and subtle sensory stimuli elements to mostly subtle sensory elements. On the other hand, *Indiana Jones 2* provided obvious sensory stimuli elements throughout the game at the beginning of each level, but then cut them out and let the players figure out major steps in the problem solving process without much guidance through use of sensory stimuli elements. As mentioned earlier, the teams were more effective collaborative problem solvers during *Portal 2* when the most of the sensory elements were subtle. They were challenged more during *Indiana Jones 2* when they encountered a sudden drop in the numbers of obvious sensory stimuli elements as they got used to solving the problems with the help of obvious sensory stimuli elements.

When it comes to the feedback function of sensory stimuli elements, the presentation might not be as relevant to the collaborative problem solving process. The games analyzed in this study showcased a big variety on how to present sensory stimuli elements as restrictive or confirmative feedback. While in *Portal 2* players' actions were restricted through a range of sensory stimuli elements such as death and re-assembling to absence of reaction for a performed action, *Indiana Jones 2* provided more obvious restrictions through not allowing players to move beyond a point or killing/bringing back a character along with absence of reaction to a performed action. In general, these restrictions and confirmations provided by the sensory stimuli elements were helpful for the teams to understand the game rules and the possible actions that they can take in the game environment. While for the inexperienced players the subtle feedback was not very helpful and they seemed to rely more on their more experienced partners, the obvious feedback elements were more easily understood and utilized. For example, in *Portal 2* some inexperienced players had trouble with the idea of not being able to shoot portals through blue force fields. The blue force fields consisted of both a subtle distinct color as feedfront informative sensory stimuli and a subtle feedback of sparks coming out after shooting a portal through them. The inexperienced players were observed to attempt shooting portals through the blue force fields many times until that behavior was corrected by their more experienced team mates.

It was also observed that even though in *Indiana Jones 2* when the obvious feedfront sensory stimuli elements disappeared the teams were challenged more and this triggered more collaborative effort to solve the problems, overall the frustration levels went up as well. In real life those points could have been the part where players either quit the game or consult online walkthroughs. However the obvious feedback allowed teams to develop another method to solve the problems. In *Indiana Jones 2*, via using the crosshair through moving it across the game screen until it changed color, both teams were able to identify what objects that they can interact with and solve the problem. In this case, something that was designed to be an obvious feedback mechanism was also used as a subtle feedfront mechanism. This allowed the teams to come up with parts of the solution but it did not promote any collaborative problem solving.

Amount of Sensory Stimuli Elements.

One thing that came out as an obvious result of this study was that not all the sensory stimuli elements were acknowledged or recognized by the teams. While some teams ignored the subtle audial cues, some teams ignored more obvious cues such as text flashing on the screen. Also the amount of utilization of sensory stimuli elements largely depended on the player’s level of expertise. For example, the first team which was relatively less experienced compare to the other teams made use of almost all the sensory stimuli elements whereas other two teams tended to ignore some subtle feedfront sensory elements such as the wall displays in *Portal 2*.

In all the games, the number of sensory stimuli elements were high at the beginning and would slowly reduce towards the later sections in the game. *Portal 2* had a linear progression, and the heavy sensory stimuli with more obvious presentation at the beginning of the game slowly reduced in the upcoming levels. However, *Indiana Jones 2* had multiple chapters with different levels where players can select to play, and every chapter had a higher number of sensory stimuli elements with obvious presentation.

In response to research question 3 – understanding the influence of presentation of game goals and rules on collaborative problem solving.

Understanding the rules of the game and anticipating what the final outcome of the game would be is an essential part of a problem solving activity. Rules dictate how the players can play the game and help players form an understanding of the problem states and possible actions. Whereas, developing a shared understanding of the game goals helped the teams to converge on solutions.

The game rules were scrutinized under two categories: Operational/system rules and procedural rules. While operational or system rules informs players about the constraints and possibilities in a given system (i.e. how the system works), procedural rules informs the players of necessary actions to be taken in order to successfully complete a task. For example a system rule might dictate that players can only shoot portals on white surfaces, and a procedural rule might inform players that to release a ball a player must press a corresponding button first. During the collaborative problem solving process the teams identified most procedural rules through conversing with partners before taking any actions while they were developing a shared understanding of the problem. However, in some cases the procedural rules were identified through trial-and-error technique where one player would perform an action without consulting his/her partner to understand the consequences of it. Trial-and-error was mostly utilized by the experienced team mate as a mechanism to come up with a solution.

Discourse about the procedural rules really played an important role in development of the joint problem space. In cases where the discrepancy between the levels of gameplay skills was noticeably higher, clearly presented procedural rules had both advantages and disadvantages for the collaborative problem solving activity. *Portal 2* had relatively simple and a clear presentation which allowed players to quickly learn the procedural rules of the game. However, this simple and clean presentation resulted with two different outcomes. In one case, one member was able to identify the procedural rules and therefore the problem states and performing the actions by himself without communicating with his partner. In another situation the clear procedural rules were helping teams with less gameplay experience to easily identify the problem states and possible actions.

System rules were not clear for the inexperienced players at first but all players developed an understanding of the system rules as they learnt how to play the game. In most cases inexperienced teammates needed help from the more experienced partners to develop a better understanding of the system rules. In a way this helped teams to reinforce their communication at the beginning of the game.

Another important aspect of joint problem space was to develop a shared understanding of the game goals. Game goal here is loosely defined as the outcome of a game section, not the overarching end goal of the whole game. It was observed that neither having a conversation about the game goal was always necessary nor having both the team mates understand the game goal in order for teams to successfully complete a game task. However in order to have an effective collaborative problem solving process, the teams needed to a) talk about the goals of the game, b) converge on a mutual understanding of game goals, and c) plan mutually agreed strategies to achieve the game goals.

Chapter 7 Summary

In this chapter, the researcher discussed the key findings of this study in two segments. The first segment conferred the design similarities and differences of three games. The emphasis of this segment was on identifying how collaborative problem solving was supported or hindered across different genres of games. In the light of the first segment and case analysis results, the second segment provided discussions on the key findings of this study. In this segment, the researcher discussed the results in response to three major research questions that are tied to the game design attributes. The discussions on the influence of three game attributes revealed information regarding the mechanisms that support the collaborative problem solving.

The next, and the final, chapter encloses the summary of these key findings. It also discusses the implication of how these findings can inform the educational game design practice. The final chapter of this dissertation concludes with suggestions for future research.

Chapter 8 - Conclusion

This study examined the relationship between essential game design attributes and the process of collaborative problem solving to explore into how to design educational games that can support collaborative learning. In order to do that, three key game attributes, level of challenge, sensory stimuli elements, and game goals and rules, were scrutinized in relation to participants' joint problem solving and assumed functional roles during gameplay.

This research utilized a cross-case study approach as a methodology that guided the data collection and analysis processes. Seven cases were formed. Each case consisted of a combination of a video game and two participants that played the video game. Analysis of the data was conducted at three levels: within game within group, and within game across groups, and across games. While within game within group analysis provided an in-depth analysis of the relationship between the game design attributes and collaborative problem solving process, within game across group and across game analyses provided more game design focused results. Also, across case comparison allowed this research to extend and discuss its findings across games with different genres and structures, considering the impossibility of including every game genre and structure in one study.

Major findings of this study confirmed the potential influence of game design attributes on collaborative problem solving process. More specifically this study revealed that sensory stimuli elements can influence collaborative problem solving through three aspects: their function (feedfront vs. feedback), their presentation (obvious vs. subtle), and their amount. It was found that the feedfront sensory stimuli elements were more effective in enhancing collaborative problem solving process when appropriately used. Through triggering conversation that possibly lead the players towards a converged solution, the feedfront sensory stimuli elements mostly helped inexperienced players during this study. On the other hand, the experienced players did not always acknowledge the feedfront sensory stimuli elements considering their low need to use sensory stimuli elements to solve problem. However, when they were challenged they resorted to the feedfront sensory stimuli elements to help complete the problem tasks. Feedback sensory stimuli elements were rarely observed to be used and only during the attempts to understand the game rules as part of developing a common understanding of the problem space. The findings regarding the presentation of the feedfront sensory stimuli indicated that the subtle sensory elements were more successful at promoting a balanced collaboration and a converged solution. The varying amount of sensory stimuli elements utilized during this study indicated that its influence was largely dependent on players' level of expertise. For inexperienced teams, extensive number of sensory stimuli elements was needed for a more enhanced collaborative problem solving experience, whereas the experienced players only needed large amounts of sensory stimuli elements when they encountered a complex problem that challenged them

In relation to that, perceived challenge levels had an influence on the collaborative problem solving process as well. It was found that when challenge levels were increased due to a complex problem task, the teams were more willing to collaborate and share their understanding of the problem even if they were not collaborative in general. However, the increased challenge due to difficult game play did not promote collaboration especially for teams with inexperienced players. Also, for experienced players difficult gameplay only results in more individualistic action taking.

The influence of clarity of game rules and goals were more intertwined with the other game design attributes of this study. While it was found that most of the game rules were discovered through trial-and-error by the experienced players which are sometimes shared with the inexperienced players, the direct impact of the presentation of the rules on collaborative problem solving process was harder to identify. Game rules were examined under two categories: Procedural rules that inform the players about the necessary actions to be taken to complete the task, and operational rules that inform players about constrains and possibilities in a given system. When the procedural rules were not clear for the one of the players in any team it triggered more conversation that helped them develop a common understanding of the problem space. Ambiguity of the procedural rules mostly meant that players were facing a complex problem task, which mentioned earlier, resulted with promoting collaboration. However, in occasion not being able to understand the procedural rules clearly inhibited the teams to converge on solutions. The gaps in the understanding of the operational rules reinforced the communication between the players through constant question and answer style conversations. Similarly the ambiguity of the game goals also increased the level of challenge for the players and therefore was promoting conversation that pushes the teams towards more collaborative approaches. However, although the ambiguous of the game goals promoted more conversation that supported collaborative problem solving, they did not always help the teams to reach a successful solution on their own.

These findings align well with some of the well-known literature in the game design field and expand this knowledge by enlarging the way these game attributes are studied in relation to collaborative problem solving. The examined game design attributes of this study are discussed mainly in a general sense and not in a specific context within the current literature. On the light of the theoretical and conceptual knowledge available in the literature, this research attempts to add more specific and empirical information to the game design literature that could potentially turn into heuristic design guidelines for collaborative educational games. These heuristic guidelines are discussed in detail in the next section.

Implications for the Instructional Design Field

Advancements in socio-cognitive learning theories have recently enabled a shift from individualistic learning approaches to collaborative learning techniques. This shift allowed educational researchers and instructional designers to focus on collaborative learning environment design. More specifically the researchers and the practitioners studied how and what kinds of instructional support strategies that can promote meaningful collaborative learning. This study provided an insight to how successful collaboration and a learning related activity can be supported through the environment's design elements. At a first glance one might think that commercial video games have nothing to offer to the more rigid academic learning environments. However, as literature suggests there is a lot to learn from successful video games in terms of how to keep the learners engaged and provide them a meaningful learning experiences. This study attempts to shine a spotlight onto some of these issues through providing heuristics for designing effective collaborative learning environments based on the lessons learnt from multiplayer video games.

General design suggestions for digital collaborative learning environments.

This section provides design suggestions for educational game design practitioners. These suggestions are generated based on the empirical evidence this research provided and are specific to designing interactive game-like learning environments for collaborative problem solving.

Blending controlled and open-ended environments.

Blend controlled environments with well-structured problems to develop collaboration and open ended game environments to provide more ill-defined problems. It is more common to use ill-defined educational problems in collaborative educational settings, and most ill-defined problems utilizes a digital environment with little or no structure that shapes the collaboration. During this study it was found that more structured games promoted collaboration by constraining the game environment, and less structured games lack the ability to shape relationships and team work between players. However, the structured environment fails to provide higher level learning exercises. Therefore, a blend of structured and less structured environments should be incorporated in collaborative educational games. Through this blend, we can initially nourish collaborative approaches and strengthen the relationships between the teammates with structured game environments and then allow them to engage in higher level learning activities with ill-defined problems that are presented in less structured games.

Breaking down learning task.

Break down the learning task into smaller, more manageable sections, but keep them all connected. What most games successfully do is that they break down the overall goal of the game into smaller tasks that are still connected to the general story of the game. This is generally done through providing a cut scene, an environmental change, or specifically defining missions that are related. This allows players to work on more manageable smaller sections, while at the same time having an understanding of the bigger picture. What this also does for the players is that it gives them a sense of accomplishment even if it is a small one and a chance to reflect back and recuperate. Other way these small breaks between tasks contribute to collaboration is through giving time for players to socialize and joke around. In the context of learning this small breaks in between tasks can be used by the teams to reflect on the collaborative actions and build social relationships. As observed in this study harmonious group dynamics is essential for effective collaborative learning.

Selecting a presentation style for sensory stimuli elements.

Select an appropriate style of presentation for the sensory stimuli elements depending on their function in the game. Subtly presented sensory stimuli elements utilized as feedfront mechanisms proved themselves to be more supportive of collaborative problem solving. The subtle clues mostly awake the players' curiosity and triggers conversation that can steer the team towards shaping a mutual understanding of the problem. On the other hand, feedback sensory stimuli elements are not as much encouraging of collaborative problem solving but are important for individual problem solving. When feedback sensory stimuli elements are obvious it is easier for the individuals to understand the operational rules of the game and contribute to problem solving activity. Therefore, the appropriate presentation of sensory stimuli depends on its utility.

Scaffolding through feedback and feedfront.

Scaffold through feedback and feedfront elements until the user knows how to navigate within the learning environment. Most games provide a tutorial section which is integrated within the story line of the game where most of the scaffolding takes place. In order for learners to get accustomed to the environment that they are using they might need more guidance at the beginning. This guidance should slowly disappear as they progress.

Providing problems with changing complexity.

Provide problems with changing complexity to provide appropriate challenge levels. Most video games successfully increase the challenge levels in a progressive manner. However, some games increase this difficulty by exposing the players to a harder gameplay through increasing the number of enemies or providing stronger enemies. This way of increasing challenge does not support collaboration as well as increasing challenge with complex problems. When a game provides complex problems it encourages both team members to contribute to the problem solving activity. In some cases the differences between team members might turn one person into being the active contributor and the other person being the passive follower. However, when the active contributor is faced with a challenging problem this allows the passive follower to become more active and assume more important roles in the collaborative problem solving process. Therefore, it is important for educational games to change complexity level of the problems to assure that passive team mates can also contribute.

Supporting complex problems with feedfront.

Complex problems should be supported with feedfront sensory stimuli elements to assure successful collaborative problem solving. During a difficult problem most teams display a higher need for the feedfront sensory stimuli elements that could guide them solve the problem faced. When the complex problem is not supported by enough feedfront elements then the players tend to get frustrated and this could influence the collaborative problem solving process negatively.

Avoiding difficult gameplay.

Avoid difficult gameplay that requires fast reaction time or extensive hand-eye coordination. Collaborative educational games should provide environments for more than one player to harmoniously work through the tasks together. When one player is inexperienced with gaming then some game tasks such as shooting enemies can become a cumbersome act that can take more precedence over the activities that are more important for the learning experience. This affects the quality of the collaboration and therefore collaborative problem solving process.

Therefore to increase the likelihood of successfully collaboration the educational collaborative games should avoid difficult game play or keep it to minimum.

Providing opportunities to discuss game goals.

Provide opportunities and encourage players to discuss the game goals. Different games have different ways to present the goals to their players, however most game do not provide an opportunity or encourage the act of sharing the understanding of the game goals with partners. Suddenly being dropped in an action scene without giving a chance to team members to develop a common understanding of the game goal might hinder the problem solving process. Therefore providing little breaks after presentation of the goal or even better providing sections where it encourages the players to discuss game goals can support the development of joint problem space and therefore help the collaborative problem solving process.

Limitations of this Study

One of the biggest limitations of this study is its inability to generalize its findings across all the genres of digital games. Even though three games from different genres were utilized in this study to expand the implications of the results across a wider span, it is nearly impossible to study all types of video games in one study. Therefore the findings of this study have limited generalizability.

Another limitation for this study was due to the fact that the data were collected in a lab setting with artificially set-up groups and this may not be representative of real-life gameplay settings. In real life educational settings groups maybe formed in a more informed manner by the teacher or by students themselves. The group members will have some acquaintance which during this research only one group possessed as an attribute. Also, in real-life settings the collaborative games may or may not be played in classroom settings. In addition, this research study utilized commercially available games that were artificially assigned to the teams based on their experiences levels and their existing knowledge of the games. This proved to be another limitation that could have been resolved if a game was specifically designed for this study. Using commercially available games also constrained the number of players in a group. The games selected for this study only allowed two players to collaboratively play the game.

Other major methodological limitations include the lack of content validity of the in-session questionnaire used in this study and the lack of a secondary coder. This study utilized a questionnaire that was formed based on a collection of questions found in the literature. The content validity of these questions in the context of previous research was conducted. However, when the new instrument that used a collection of these questions was formed the content validity was not studied. In addition, coding process was conducted by one researcher. Therefore, this research lacks the verification of the research codes by a secondary coder.

Finally, this study by nature fails to provide the basis for establishing causality due to its methodology. The aforementioned relationships between the game design attributes and collaborative problem solving process are not comprehensive of confounding factors. This study merely lays out the potential relationships between the variables that are of focus based on observational data and hopes to contribute to the conversation of how we can better design collaborative educational games. This study also acknowledges the limitation of not being able to include all the variables that could play a role. For example, among many, the influence of time or age was not discussed during this study.

Suggestions for Future Studies

This study identified a number of important arguments that supported the design of educational collaborative game environments through studying three games from different genres and with different structures. Future research that extends the findings of this study onto additional genres of games may be necessary to make more generalized conclusions. In addition, this study can also expanded through including more number of game attributes to provide a completer picture of how game design can influence the learning. Also, it would be beneficial for future studies to adapt a more-controlled design to understand the causality between the game design attributes and collaborative problem solving. This study took an exploratory approach to understand how the design elements of digital games influenced collaborative problem solving processes. The findings of this study can inform a quantitative study where the suggested mechanisms can further be validated through modeling.

In addition, more specific design suggestions can be made after studying more specific target groups. This study by design only included young adults and incorporated games that could cater to wide range of audiences, which then provided generic design suggestions based on the conclusions of this study. Future studies can focus on specific groups of audiences based on age groups or grade levels to identify the influence of game attributes that are particularly essential for those groups.

Appendix A: Game Analysis Sheet

Game Name: **Game Type:**
Game Plot:
Mission Indicator (name, or assigned number):
Mission Statement:

Nature of the Problems	**Type of the Problem**	**Nature of Collaboration**

Level of Challenge	**Clarity of the goal of the mission**	**Clarity of the rules**
(Low, Medium, High)	(Clear – presented, clear – repetitive, vague)	*System Rules*
		Procedural Rules
		Notes:

Sensory Stimuli Elements	
Content	**Type**
e.g. Cut-screen clip	Directive feedfront
e.g. Text appearing on screen	Directive feedfront
e.g. Visual cues (Anything that happens in the storyline of the game)	Informative feedback
e.g. Auditory cues	Confirmatory feedback

Notes:

Appendix B: Example Transcription/Coding of Gameplay Video Data

GROUP 1 - level 7 - in the room underground			start	0:05:50	end	0:18:25	Game Elements				
FUNC ROLE	Relation	ENTITY	Relation	Related Entity	Relation	Related Entity	Corresponding Feedback	Rules & Goals	Sensory Elements	JPS	Other
A-P A-I [PLACE]		Staff of Ra	under	Light					After the cut scene Tom: Now we have a staff of Ra which I think we can put"	Liz: "We have to build something."	
B-E [JUMP IN]		Snake pit	dies				T1: Some characters have phobias and will panic so find a way to clear a path. Remember small creatures will avoid fire.;			Tom: "Well I can move the beam around again. I just don't know what I am supposed to be pointing at yet."	
A-E [FALL IN]		Snake pit	dies						Tom: "Oh god snakes (seeing the green snakes)."		
B-E [FALL IN]		Snake pit	dies						Liz: "Oh what is this? Fire (actually it is just a pool of red snakes)" Tom: "Yeah." After seeing the text on the screen Tom: "Oh no it is a snake pit. All that red stuff is a snake pit. So I can't go in there. Because my character freaks out at snakes."	Liz: "Oh what is this? Fire (actually it is just a pool of red snakes)" Tom: "Yeah." After seeing the text on the screen Tom: "Oh no it is a snake pit. All that red stuff is a snake pit. So I can't go in there. Because my character freaks out at snakes."	How sensory elements helping them shape their understanding
B-E [FALL IN]		Snake pit	dies					Tom: "So we go in there, we die."			
A-P B-I [DIG]		ground	reveals	moving legos			Sparkles			Tom: "Also, there is stuff. I think you can dig over here. See how the ground is shiny"	
A-P A-I B-I [BUILD]		moving legos					Moving Legos			Tom: "Oh nice and that stuff (moving legos) we can build."	
A-P A-I B-I [PUSH]		built lego pile							Liz: "Can we go up there?" Tom: "It is also on a checker so we can push it." Liz: "Maybe."	Liz: "Can we go up there?" Tom: "It is also on a checker so we can push it." Liz: "Maybe."	

A-E [PUNCH]		object	yields	moving legos						While they were trying to push it Liz presses a wrong control button and by mistake punches something behind which drops down a big pile of moving legos. Tom: "Or this is all more stuff to build."	
A-E B-E [BUILD]		moving legos									
A-P A-I [PUSH]		Statue w/ reflector							Liz: "What is this? (white arrow)" Tom: "That's the spot where I have to put the staff."	Tom: "There is our reflector person once we have the staff of Ra. Now he I bet wants to go over to the other side. Because then. (the statues settles down at the end of the checker board path) Yeah"	
A-I [PLACE]		Staff of Ra	under	Light	directing to	reflector				Tom: "Now I don't know what it does."	
A-E [CLIMB]											
B-E [BEAT]		Snakes						Tom: "Oh you can kill them. that's great you can kill the snakes."			
B-E [BEAT]		Snakes								Tom:"I feel like we should do something here (raised up platform with the light shining on) but I don't know."	
B-E [BEAT]		Snakes									
B-E [BEAT]		Snakes									
B-E [BEAT]		Snakes									
A-E [PLACE]		Staff of Ra	under	Light	directing to	everywhere					
B-E [BEAT]		Snakes									
B-E [BREAK]		Objects									

A-E [PLACE]		Staff of Ra	under	Light	directing to	reflector		When Liz tries to go to the other side of the room to see where the beam is hitting, she pulls Tom with him and he loses his location. The game doesn't not allow split screen in this section and forces them to be confined in close vicinity from each other.		Tom:"So when I do that (reflecting the beam towards the reflector dish on the statue) where does the beam go? Can you go to the other side to see that?"	
A-E B-E [BREAK]		Objects								While Tom is smashing the objects in the game to collect more coins he opens up a chest with a statue in it. Tom: "Oh another statue."	
B-E [BEAT]		Snakes									
A-E [WHIP]		Chest	reveals	reflector dish							
A-E [OBTAIN]		reflector dish								Liz: "And we have another..." Tom: "We have another reflector dish." Liz: "Reflector."	
B-P A-I [DROP]		reflector dish								Liz: "What is right here?" Tom:"Can I put it here?" Liz: " Can you put it there?" After he tries, Tom: "I would love to but." Liz: "It won't let you?" Tom:"Yeah."	
A-E [PICK UP]		reflector dish								While walking around with the reflector dish in his hand Tom sees a white arrow flashing on top of the snake pit. Tom: "Oh there is where I am supposed to put it."	

A-P A-I [DROP]		reflector dish	into	Snake Pit			White Arrow Flashing			When he tried to put the dish on the spot with the arrow, the dish falls into the snake oit. Tom: "That didn't work." Then he takes one more step and falls into the snake pit himself. Tom: "So we have to clear the snake pit."	
A-E [FALL IN]		Snake Pit	kills								
A-P											
B-T [JUMP]	into	Snake pit	kills					Liz: "I thought jumping into it would." Tom: "Fire maybe?"			
B-E [BREAK]		Objects								Tom:"How do we? Yeah, because we have to clear out that snake pit, so when we wanna do anything else we can"	
A-P A-S											
B-E [BREAK]		Objects								Liz: "I am chopping all around us." Tom: "Yeah that's a good thing."	
A-E [CLIMB]											
A-E [OBTAIN]		Torch					Blue arrow Flashing			Liz: "Oh you got up there. What is that?" Tom: "Fire. And I bet when I have fire I can clear this snake pit. Yeah"	
A-P A-I [WALK]	into	Snake Pit	with	Fire	clears	Snakes					
A-E [PLACED]		Torch	keeps	snakes	away		White arrow flashing			Tom: "Now that I have done that, we leave the torch in there, the snakes go away. Liz: "And then..." Tom: "And then we can go get that reflector dish and put it in its holder." Liz: "Right there?" Tom: "Right there."	
B-E [PICK UP/PLACE]		Torch									

A-P A-I [PICK UP]		reflector dish									
A-I [DROP]		reflector dish	falls	into	empty snake pit					Tom: "That didn't work." Liz: "What?" Tom: "What about..." Liz: "Put it right here?" Tom: "No because look whenever you pick that (reflector dish) up, the little arrow here starts flashing on that pulley thing there."	
B-P A-C A-S B-E [PICK UP/DROP OFF]		reflector dish									
B-E [PICK UP]		reflector dish								Tom: "I feel like there is gotta be a way to turn this key."	
A-P A-E [PICK UP/PLACE]		Torch								Tom: "There is gotta be a key or something...hmm." Liz: "We can't whip it up there?" Tom: "We can try. I am here I can try (he takes out the whip and the crossheir only appears on his partner) Only target here is you that I can whip." Liz: "Maybe whip that and try. I don't know." Tom: "Yeah I mean. (He whips her.) That just ties you up. Sorry."	
A-P B-P A-T [WHIP]		Partner									

Appendix C: In-Session Questionnaire

Game Play Questionnaire – Mission 1: Fresh off the Bus

1. Level of Challenge:	0-Not At All	1-Slightly	2- Moderately	3-Fairly	4-Extremely
a. I thought it was hard	◯	◯	◯	◯	◯
b. I felt anxious	◯	◯	◯	◯	◯
c. I felt challenged	◯	◯	◯	◯	◯
d. I felt time pressure	◯	◯	◯	◯	◯
e. I had to put a lot of effort into it	◯	◯	◯	◯	◯
f. I felt bored while playing the game	◯	◯	◯	◯	◯
g. The challenge level was adequate	◯	◯	◯	◯	◯

2. Clarity of the Goals & Rules	1- Not Clear/Easy At All				5-Very Easy/Clear	(NA)
a. How clear was the overall mission goal?	◯	◯	◯	◯	◯	◯
b. How clear were the intermediate mission goals?	◯	◯	◯	◯	◯	◯
c. How easy was it for you to be able to understand the overall mission?	◯	◯	◯	◯	◯	◯
d. How easy was it to operate through the game world?	◯	◯	◯	◯	◯	◯
e. How clear were you about the actions that can be taken in this game?	◯	◯	◯	◯	◯	◯
f. How clear were you about the application of the real world common sense rules into this game?	◯	◯	◯	◯	◯	◯

Appendix D: Before-Session Questionnaire

1. Age: ________	2. Gender: ☐ Female ☐ Male
3. Gaming Experience:	
a. Have you ever played or do you currently play video games? ☐ Yes ☐ No (Skip to question 3b)	
i. If yes, how often do you play video games? ☐ Everyday ☐ A few times a week ☐ A few times a month ☐ A few times a year ☐ I used to play when I was younger but I don't play anymore	
ii. How would you identify your level of expertise on playing video games? ☐ I am an expert gamer ☐ I am an intermediate gamer ☐ I am an novice gamer	
iii. Do you own a video game console? (Check all that applies) ☐ **Yes**, I own an XBOX ☐ **Yes**, I own a Play Station ☐ **Yes**, I own a Wii ☐ **Yes**, I own some other brand video game console ☐ **No**, I do not own a video game console	
iv. How comfortable are you with playing games on an XBOX? ☐ Very comfortable ☐ Comfortable ☐ Somewhat comfortable	

☐ Not comfortable
☐ Not sure - I have never played a video game on XBOX

v. How comfortable are you with playing games on a Play Station 3?

☐ Very comfortable
☐ Comfortable
☐ Somewhat comfortable
☐ Not comfortable
☐ Not sure - I have never played a video game on Play Station 3

vi. What types of video games do you generally play?

☐ Adventure/action games
☐ Role playing games (RPGs)
☐ First-third person shooter game
☐ Platform games
☐ Other type of games

vii. Do you play co-op video games?

☐ Yes ☐ No

b. Do you play other forms of digital games (Computer games/ games on handheld devices etc.)?

☐ Yes ☐ No

THANK YOU!

APPENDIX E: Data Analysis Codes

1- Functional Roles:
   a. Executing: Executing an action in the game environment without discussing it with partner.
   b. Proposing: Proposing or suggesting an idea or an action to the partner.
   c. Implementing: Implementing or performing an action based on proposed idea.
   d. Accepting: Accepting the proposed idea of the partner.
   e. Modifying: Modifying the initially proposed idea to build on the solution.
   f. Contesting: Contesting and questioning the proposed or suggested idea.
   g. Rejecting: Directly rejecting the proposed idea or suggestion.
   h. Testing: Testing a proposed solution to examine if it works.
   i. Reasoning: Providing a reason for a proposed or suggested idea.
   j. Explaining: Explaining partner how to play the game, or what controller keys to press.

2- Sensory Stimuli Elements
   a. Feedfront: Sensory stimuli elements that are provided for guidance purposes.
   b. Feedback: Sensory stimuli elements that are provided as a reaction to players' actions.
   c. Subtle: Sensory stimuli elements those are subtle in presentation.
   d. Obvious: Sensory stimuli elements those are obvious in presentation.
   e. Directive: Sensory stimuli elements that directs players to a solution or part of a solution.
   f. Informative: Sensory stimuli elements that informs players about the game environment and possible game objects that will be used during problem solving.
   g. Confirmative: Sensory stimuli elements that is given after an action to confirm or unconfirmed prosecuted action.
   h. Constrictive: Sensory stimuli elements that indicated the constriction in the game environment.

3- Challenge
   a. Complex Task: Challenge encountered due to a complex task.
   b. Difficult Gameplay: Challenge encountered due to a difficult gameplay.

4- Rules and Goals
   a. Procedural Rules: Rules that dictate what steps needs to be taken to solve the problem.
   b. Operational Rules: Rules that define the game environment.
   c. Clear Goals: Goals those are clear to the players.
   d. Repetitive Goals: Goals that repeats through sections of the game.
   e. Vague Goals: Goals those are not clear to the players.

APPENDIX F: IRB Approval

SYRACUSE UNIVERSITY
Institutional Review Board
MEMORANDUM

TO: Alan Foley
DATE: August 22, 2011
SUBJECT: **Submitted for Expedited Review-Determination of Exemption from Regulations**
IRB #: 11-207
TITLE: *The Influence of Game Design on the Collaborative Problem Solving Process: A Cross-Case Study of Multi-Player Collaborative Game-play Analysis*

The above referenced application, submitted for expedited review has been determined by the Institutional Review Board (IRB) to be exempt from federal regulations as defined in 45 C.F.R. 46, and has been evaluated for the following:

1. determination that it falls within the one or more of the five exempt categories allowed by the organization;
2. determination that the research meets the organization's ethical standards.

This protocol has been assigned to exempt category **2** and is authorized to remain active for a period of five years from **August 22, 2011** until **August 21, 2016**.

CHANGES TO PROTOCOL: Proposed changes to this protocol during the period for which IRB authorization has already been given, cannot be initiated without additional IRB review. If there is a change in your research, you should notify the IRB immediately to determine whether your research protocol continues to qualify for exemption or if submission of an expedited or full board IRB protocol is required. Information about the University's human participants protection program can be found at: http://orip.syr.edu/human-research/human-research-irb.html. Protocol changes are requested on an amendment application available on the IRB web site; please reference your IRB number and attach any documents that are being amended.

STUDY COMPLETION: The completion of a study must be reported to the IRB within 14 days.

Thank you for your cooperation in our shared efforts to assure that the rights and welfare of people participating in research are protected.

Tracy Cromp, M.S.W.
Director

Note to Faculty Advisor: This notice is only mailed to faculty. If a student is conducting this study, please forward this information to the student researcher.
DEPT: Instructional Design, Development & Evaluation, 330 Huntington Hall **STUDENT:** Nilay Yildirim

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References

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Wilson, K.A., Bedwell, W.L., Lazzara, E.H., Salas, E., Burke, C.S., Estock, J.L., Orvis, K.L., Conkey, C. (2009). Relationships between game attributes and learning outcomes. Simulation and Gaming. 40(2), 217–266.

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Zagal, J., Rick, J., & Hsi, I. (2006). Collaborative games: Lessons learned from board games. Simulation & Gaming, 37, 24-40.

Vita

Nilay Yildirim, Ph.D.

Education

Ph.D. 2013, Syracuse University
School of Education
Major: Instructional Design, Development and Evaluation

M.S. 2007, Syracuse University
School of Education
Major: Instructional Design, Development and Evaluation

M.S. 2004, Cukurova University, Turkey
School of Education
Major: Mathematics Education

M.S. 2003, Cukurova University, Turkey
School of Arts & Sciences
Major: Mathematics

Work Experiences

2008 – Present Syracuse University – Institutional Research & Assessment
Research Analyst /Statistician

2007 – 2008 Syracuse University – Imagining America
Research Assistant

2007– 2008 Syracuse University – School of Education
Graduate Assistant

2007– 2007 Department of Health – AIDS Institute
Student Intern/Marketing and Training

2006– 2006 Syracuse University – Training System Institute
Research Assistant/External Evaluator

2006– 2006 Manufacturers Association of Central New York
Intern/Survey Developer

Grants and Awards

- School of Education Creative Research and Grant, Syracuse University (2011), $800.00.
- Enrollee of Future Professoriate Program (FPP - is a university teaching certification program that aims to prepare graduate students for the necessary responsibilities of the professoriate position) (2010-2012).
- Recipient of Quasi-Experimental Design and Analysis in Education training workshop. Sponsored by Institute of Education Sciences (IES) (2010).
- Recipient of prestigious Ministry of Education Scholarship, Turkey (2004).

Teaching Experiences

2010 - 2012 School of Education, Syracuse University

Co-instructor:
EDU 800 - Structural Equation Modeling and Factor Analysis
IDE 800 - Design-Based Research
IDE 761 - Strategies in Educational Project Management

Guest Lecturer:
EDU 647 - Statistical Thinking

2000 - 2004 Zafer Private School, Adana Turkey
K 7-12 Mathematics
K 7-12 Geometry
K 7-12 Statistics

Publications

Johnson, D. R., Wasserman, T., **Yildirim, N**., Yonai, B. (2012) Examining the Effects of Stress and the Campus Climate on Persistence: A Test of Bean and Eaton's Psychological Model of College Student Retention. Publication accepted to Research in Higher Education.

Ke, F., **Yildirim, N.**, Enfield, J. & Ke, F. (2012). Exploring the Design of Game Enjoyment through the Perspectives of Novice Game Developers. International Journal of Gaming and Computer-Mediated Simulations, 4(4).

Foley, A. & **Yildirim, N.** (2011). The Research on Games and Instructional Design. Academic Exchange Quarterly, 15(2).

Peer-Reviewed Conference Presentations

Yildirim, N & Wasserman, T. (2011). Supplementary Factor Analysis of NSSE Data. Paper Presentation at the meeting of Association for Institutional Research, Toronto, ON.

Yildirim, N. (2011).Examining the National Survey of Student Engagement (NSSE) Questionnaire Items. Paper Session accepted to the meeting of American Educational Research Association, New Orleans, LA.

Yildirim, N., & Enfield, J. (2011). What is Problem Solving in the Context of Action/Adventure Games? Poster Session presented at the meeting of Games for Learning, Madison, WI.

Yildirim, N., Enfield, J. & Ke, F. (2011). Exploring the Key Factors of Game Design Process: Player Enjoyment. Poster Session presented at the meeting of Games for Learning, Madison, WI.

Yildirim, N. (2010). Understanding the Relationship between Game Play and Problem Solving. Poster session presented at the meeting of Association for Educational Communications and Technology, Anaheim, CA.

Yildirim, N. (2009). When Instructional Design Meets Entertainment. Poster session presented at the meeting of Association for Educational Communications and Technology, Louisville, KY.

Yildirim, N. (2008). Elements of and Educational Game. Poster session presented at the meeting of Association for Educational Communications and Technology, Orlando, FL.

Statistical and Programming Skills

- Statistical Software Packages: SPSS.
- Statistical programming language: SAS.
- Specific software for data analysis: AMOS, Mplus, Tableau.
- Languages and Software: HTML, CSS.
- Other computational programming language used: Visual Basic.

Professional Services

- Copy Editor, Journal of International Students (2013).
- Reviewer, Journal of International Students (2011 – 2013).
- Organizer, Global Game Jam (2011-2013).
- Session facilitator, Association for Communications and Educational Technology paper session (2010).
- Reviewer, Association for Communications and Educational Technology conference proposals (2010).
- Participants, Social Media Design Charrette. Syracuse University (2010).
- Organizer, Imagining America's Tenure Team Initiative Working Conference (2008).
- Coordinator, Field Trips for international visiting student groups to Syracuse University (2008).
- Coordinator, new-coming student orientations (2007, 2008, & 2009).
- Representative, IDD&E Graduate Student Representative (2006 - 2007).
- Member, American Educational Research Association (2006-2013).
- Member, Association for Institutional Research (2010 -2013).
- Member, Association for Communications and Educational Technology (2006-2012).

Professional Development and Training

- An Intensive Introduction to Data Mining in Institutional Research, Association for Institutional Research (AIR) (2013)
- Data Mining: Clustering Techniques and Predictive Modeling , Association for Institutional Research (AIR) (2013)
- Future Professoriate Program (FPP - is a university teaching certification program that aims to prepare graduate students for the necessary responsibilities of the professoriate position) (2010-2012).
- Quasi-Experimental Design and Analysis in Education training workshop. Sponsored by Institute of Education Sciences (IES) (2010).